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Land Disposal of Sewage Sludge

Volume VI

Research Report No. 90

Research Program for the Abatement of Municipal Pollution
under Provisions of the Canada-Ontario Agreement
on Great Lakes Water Quality

CANADA-ONTARIO AGREEMENT

RESEARCH REPORTS

These RESEARCH REPORTS describe the results of investigations funded under the Research Program for the Abatement of Municipal Pollution within the provisions of the Canada-Ontario Agreement on Great Lakes Water Quality. They provide a central source of information on the studies carried out in this program through in-house projects by both Environment Canada and the Ontario Ministry of Environment, and contracts with municipalities, research institutions and industrial organizations.

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LAND DISPOSAL OF SEWAGE SLUDGE

VOLUME VI

(April 1, 1977 - March 31, 1978)

by

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RESEARCH PROGRAM FOR THE ABATEMENT
OF MUNICIPAL POLLUTION WITHIN THE
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ABSTRACT

The objective of this research was to determine maximum rates of sewage sludge application which can be used on agricultural soil without contaminating subsurface water with nitrate nitrogen and surface waters with elements pathogenic to humans and animals, and without reducing the yield or quality of the crops produced.

This volume, which covers the period from April 1, 1977 to March 31, 1978, discusses the results from five years of field runoff studies with fall, winter and spring applied fluid sewage sludge on land cropped with grain corn. Nutrients and metals in runoff water were measured. The report also covers the fifth year of field rate and source studies with sludges resulting from treatment of sewage with calcium hydroxide, ferric chloride and aluminum sulphate for phosphorus removal. One experiment involved surface sludge applications on a loam soil on which bromegrass was grown, and two experiments involved corn on a loam and a sandy loam. In a greenhouse experiment, six fluid sewage sludges, selected for their high metal content, were applied to a sandy loam soil. Eleven crops of ryegrass were grown with sludge added before each crop. Half of the treatments received no sludge after the fifth crop. Crop growth and nutrient and metal uptake were studied.

Runoff losses continued to be small, with generally less than 2 kg N or 1 kg P/ha lost in one year. Rainfall and winter frost conditions appear to be more important than total precipitation in determining runoff losses. Sludge application in winter did not create added hazards, provided reasonable precautions were taken.

In the field rate and source studies the bromegrass and corn yields were slightly more with sludge than with ammonium nitrate.

The sludges increased sodium bicarbonate-extractable (plant available) soil phosphorus markedly, with the calcium sludge being much more effective than the other sludges. Phosphorus concentrations in the crops were high, and little affected by treatment.

Cadmium content of both grass and corn stover was increased by sludge application - greatest with the aluminum and iron sludges.

Chromium was increased in some plant tissues at some sites. Copper, nickel, zinc and molybdenum concentrations in bromegrass and corn stover increased with high rates of sludge application. Metal concentration in corn grain was little affected by treatment.

In the greenhouse study, increased rates of sludge applied at one time increased the concentrations of metals in ryegrass, with the exception of antimony, mercury and selenium. Repeated cycles of sludge application and cropping did not increase metal concentrations in the ryegrass from one crop to the next at any of the rates studied. One exception to this was zinc, which showed some increase in content from one crop to the next with one sludge very high in zinc.

The metal concentrations in ryegrass receiving different sludges frequently did not correspond to the amounts of metals added. The metals in different sludges, therefore, differ in availability either because they are in different chemical form or because their uptake is influenced by other factors which differ from one sludge to another.

RÉSUMÉ

Cette recherche visait à déterminer les épandages maximaux de boues résiduaires possibles sur un sol agricole sans contaminer l'eau souterraine par l'azote nitrique, ni les eaux de surface par des composés pathogènes pour l'homme et les animaux, ni réduire non plus la production et la qualité des récoltes.

Le présent document, qui porte sur la période du 1er avril 1977 au 31 mars 1978, analyse les résultats de recherches menées pendant cinq ans sur le ruissellement. Les terres étudiées, cultivées en maïs à grain, ont reçu des épandages de boues résiduaires liquides à l'automne, à l'hiver et au printemps. On a dosé les éléments nutritifs et les métaux présents dans l'eau de ruissellement. Le rapport fait aussi état de la cinquième année d'études où l'on a tenu compte des amendements et de la nature de boues déphosphatées à l'hydroxyde de calcium, au chlorure ferrique et au sulfate d'aluminium. Dans une expérience, on a traité un sol limoneaux destiné à la culture du brome et, dans deux autres, des sols limoneux et limoneux-sableux réservés à la culture du maïs. En serre, on a également amendé un limon sableux de six boues résiduaires liquides, choisies pour leur haute teneur en métaux. On a effectué 11 récoltes d'ivraie de Perse sur un sol enrichi de boues entre chaque récolte. Dans la moitié des cas, les traitements ont cessé après la cinquième récolte. On a étudié la croissance des plantes et leur absorption d'éléments nutritifs et de métaux.

Les pertes par ruissellement sont demeurées négligeables, s'établissant annuellement à moins de 2 kg de N ou 1 kg de P/ha. Le gel hivernal et la fréquence des precipitations semblent déterminer les pertes dues au ruissellement beaucoup plus que la quantité totale de pluie. Les risques de contamination n'ont pas augmenté à la suite de l'épandage prudent de boues en hiver.

Compte tenu des épandages et de la nature des boues, les récoltes de brome et de maïs ont été légèrement plus élevées avec les boues qu'avec du nitrate d'ammonium.

Dans le sol, les boues ont augmenté notablement la quantité de phosphore extractible par le bicarbonate de soude (phosphore assimilable

par les plantes). Les boues de calcium ont, de loin, donné le meilleur rendement. La teneur en phosphore des plantes récoltées était élevée et peu modifiée par les traitements.

Dans les graminées et le maïs à fourrage, la concentration de cadmium a augmenté à la suite de l'épandage de boues, et, de la façon la plus marquée, avec les boues d'aluminium et de fer. A certains endroits, la teneur en chrome des tissus végétaux s'est élevée. Dans le brome et le maïs à fourrage, les concentrations de cuivre, de nickel, de zinc et de molybdène ont augmenté en fonction du nombre d'épandages. La teneur en métaux du maïs en grain n'a guère varié à la suite de ces traitements.

En serre, l'application d'une dose plus forte de boues accru la concentration des métaux dans l'ivraie de Perse, sauf celle d'antimoine, de mercure et de sélénium. Malgré l'épandage répété de boues et les multiples récoltes, la teneur en métaux de l'ivraie de Perse n'a pas augmenté d'une récolte à l'autre, indépendamment du nombre d'épandages. Seul le zinc a fait exception; il s'est concentré d'une récolte à la suivante, après l'application d'une boue très riche en ce métal.

Il est arrivé souvent que, dans l'ivraie de Perse, les concentrations métalliques ne correspondent pas à la teneur en métaux des différentes boues. Il semble donc que la capacité d'assimilier les métaux varie selon le type de boue. Elle peut dépendre des différentes formes chimiques sous lesquelles se trouvent les métaux, ou d'autres facteurs qui diffèrent d'une boue à l'autre.

TABLE OF CONTENTS

Page

1. INTRODUCTION 1

2. OBJECTIVES 2

3. RUNOFF 3
3.1 Objectives 3
3.2 Experimental 3
3.2.1 Design 3
3.2.2 Water analysis 3
3.3 Results and Discussion 4
3.3.1 Crop yield 4
3.3.2 Precipitation and runoff losses 4
3.4 Conclusions 5
3.5 Five Year Summary 5

4. FIELD RATE AND SOURCE EXPERIMENTS 17
4.1 Objectives 17
4.2 Materials and Methods 17
4.2.1 General 17
4.2.2 Bromegrass, Elora 17
4.2.3 Corn, Elora and Cambridge 18
4.3 Results and Discussion 18
4.3.1 The 1977 season 18
4.3.2 Nitrilotriacetic (NTA)-extractable Cd, Cu, Ni and Zn from surface soil (0-15 cm) 23
4.3.3 Summary and conclusions 24

5. GREENHOUSE EXPERIMENT 105
5.1 Objectives 105
5.2 Materials and Methods 105
5.3 Results and Discussion 105
5.4 Summary and Conclusions 110

APPENDIX - SOIL CHARACTERIZATION 173

LIST OF TABLES

Table		Page
1	Yield of Corn Grain in 1973, 1974, 1975, 1976 and 1977.	7
2	Monthly and Cumulative Precipitation for the Elora Research Station, 1977.	8
3	Rainfall in Winter Period, Elora (January 1 to May 12, 1977).	9
4	Rainfall in Summer Period, Elora (May 13 to November 20, 1977).	10
5	Runoff Losses in Winter Period (January 1 - May 12, 1977). Total and Soluble Nitrogen and Phosphorus.	12
6	Runoff Losses in Summer Period (May 13 - November 19, 1977). Total and Soluble Nitrogen and Phosphorus.	13
7	Soluble and Acid-Extractable Metals in Runoff - Winter 1977.	14
8	Soluble and Acid-Extractable Metals in Runoff - Summer 1977.	15
9	COD in Runoff Water for Winter and Summer Periods, 1977.	16
10	Chemical Composition of Sludges Obtained from Treatment Plants on Various Dates (fluid weight basis).	26
11	Total Amounts of Various Constituents in Sludges Added to Bromegrass Experiment in First Application and Total of Three Applications at 200 kg N/ha/annum in 1977.	28
12	Total Amounts of Various Constituents Added to Bromegrass Experiment by Annual Application of Various Sludges at 178 lb N/ac (200 kg N/ha) from 1973 to 1977.	29
13	Total Amounts of Various Constituents Added in Sludges in 1977 at 178 lb N/ac (200 kg N/ha) to Corn Experiment at Elora.	30
14	Total Amounts of Various Constituents Added to Elora Corn Experiment by Annual Application of Various Sludges at 178 lb N/ac (200 kg N/ha) from 1973 to 1977.	31
15	Total Amounts of Various Constituents Added in Sludge in 1977 at 1978 lb N/ac (200 kg N/ha) to Corn Experiment at Cambridge.	32

LIST OF TABLES (CONT'D)

Table		Page
16	Total Amounts of Various Constituents Added to the Cambridge Corn Experiment by Annual Application of Various Sludges at 178 lb N/ac (200 kg N/ha) from 1973 to 1977.	33
17	Dates of Sludge and Nitrogen Fertilizer Applications and Forage Harvest, Bromegrass Experiment, 1977.	34
18	Field Operations on Rate and Source of Sludge Experiments with Corn, 1977.	35
19	Dry Matter Yield of First Cut (June 8), Bromegrass. Elora, 1977.	36
20	Dry Matter Yield of Second Cut (July 20), Bromegrass. Elora, 1977.	37
21	Dry Matter Yield of Third Cut (September 6), Bromegrass. Elora, 1977.	38
22	Total Dry Matter yield of Bromegrass (3 cuts). Elora, 1977.	39
23	Total Dry Matter Yield of Bromegrass (3 cuts). Elora, 1976.	40
24	Total Dry Matter Yield of Bromegrass (3 cuts). Elora, 1975.	41
25	Total Dry Matter Yield of Bromegrass (3 cuts). Elora, 1974.	42
26	Effect of Rate and Source of Nitrogen on Corn Stover Yield from Elora, 1977.	43
27	Effect of Rate and Source of Nitrogen on Corn Stover Yield from Cambridge, 1977.	44
28	Effect of Rate and Source of Nitrogen on Corn Grain Yield from Elora, 1977.	45
29	Effect of Rate and Source of Nitrogen on Corn Grain Yield from Cambridge, 1977.	46
30	Nitrogen Concentration in First Cut (June 8), Bromegrass. Elora, 1977.	47
31	Nitrogen Concentration in Corn Stover. Elora, 1977.	48
32	Nitrogen Concentration in Corn Stover. Cambridge, 1977.	49

LIST OF TABLES (CONT'D)

Table		Page
33	Nutrient Content of Corn Grain, Elora and Cambridge, 1977.	50
34	Nitrate-N Concentration in First Cut (June 8), Bromegrass. Elora, 1977.	51
35	Nitrate-N Concentration in Corn Stover. Cambridge, 1977.	52
36	Phosphorus Concentration in First Cut (June 8), Bromegrass. Elora, 1977.	53
37	Phosphorus Concentration in Corn Stover. Elora, 1977.	54
38	Phosphorus Concentration in Corn Stover. Cambridge, 1977.	55
39	Sodium Bicarbonate-Extractable Phosphorus in Surface Soil (0-6 in). Bromegrass Experiment. Fall, 1977.	56
40	Sodium Bicarbonate-Extractable Phosphorus in Surface Soil (0-6 in). Corn Experiment. Elora, 1977.	57
41	Sodium Bicarbonate-Extractable Phosphorus in Surface Soil (0-6 in). Corn Experiment. Cambridge, 1977.	58
42	Potassium Concentration in First Cut (June 8), Bromegrass. Elora, 1977.	59
43	Potassium Concentration in Corn Stover. Elora, 1977.	60
44	Potassium Concentration in Corn Stover, Cambridge, 1977.	61
45	Ammonium Acetate-Extractable Potassium in Surface Soil (0-6 in). Bromegrass Experiment. Fall, 1977.	62
46	Ammonium Acetate-Extractable Potassium in Surface Soil (0-6 in). Corn Experiment. Elora, 1977.	63
47	Calcium Concentration in First Cut (June 8), Bromegrass. Elora, 1977.	64
48	Ammonium Acetate-Extractable Calcium in Surface Soil (0-6 in). Bromegrass Experiment. Fall, 1977.	65
49	Ammonium Acetate-Extractable Calcium in Surface Soil (0-6 in). Corn Experiment. Elora, 1977.	66
50	Ammonium Acetate-Extractable Calcium in Surface Soil (0-6 in). Corn Experiment. Cambridge, 1977.	67

LIST OF TABLES (CONT'D)

Table		Page
51	pH of Surface Soil (0-6 in). Bromegrass Experiment. Fall, 1977.	68
52	pH of Surface Soil (0-6 in). Corn Experiment. Elora, 1977.	69
53	pH of Surface Soil (0-6 in). Corn Experiment. Cambridge, 1977.	70
54	Magnesium Concentration in First Cut (June 8). Bromegrass. Elora, 1977.	71
55	Effect of Source of Nitrogen on Magnesium Concentration in Corn Stover, 1977.	72
56	Ammonium Acetate-Extractable Magnesium in Surface Soil (0-6 in). Bromegrass Experiment. Fall, 1977.	73
57	Ammonium Acetate-Extractable Magnesium in Surface Soil (0-6 in) Corn Experiment at Elora, 1977.	74
58	Manganese Concentration in First Cut (June 8). Bromegrass. Elora, 1977.	75
59	Manganese Concentration in Corn Stover. Elora, 1977.	76
60	Boron Concentration in First Cut (June 8). Bromegrass. Elora, 1977.	77
61	Cadmium Concentration in First Cut (June 8). Bromegrass. Elora, 1977.	78
62	Cadmium Concentration in Corn Stover. Elora, 1977.	79
63	Cadmium Concentration in Corn Stover. Cambridge, 1977.	80
64	Metal Content of Corn Grain from Selected Treatments, Elora and Cambridge, 1977.	81
65	Cadmium Concentration in First Cut of Bromegrass from Selected Treatments from 1973 to 1977 Inclusive.	82
66	Cadmium Concentration in Corn Stover from Elora and Cambridge from 1973 to 1977 Inclusive.	83
67	Chromium Concentration in First Cut (June 8). Bromegrass. Elora, 1977.	84

LIST OF TABLES (CONT'D)

Table		Page
68	Chromium Concentration in Corn Stover. Cambridge, 1977.	85
69	Copper Concentration in First Cut (June 8). Bromegrass. Elora, 1977.	86
70	Copper Concentration in Corn Stover. Elora, 1977.	87
71	Copper Concentration in Corn Stover. Cambridge, 1977.	88
72	Copper Concentrations in First Cut of Bromegrass from Selected Treatments from 1973 to 1977 Inclusive.	89
73	Copper Concentrations in Corn Stover from Elora and Cambridge, 1973 to 1977 Inclusive.	90
74	Nickel Concentration in First Cut (June 8). Bromegrass. Elora, 1977.	91
75	Nickel Concentration in Corn Stover. Elora, 1977.	92
76	Nickel Concentration in Corn Stover. Cambridge, 1977.	93
77	Nickel Concentrations in First Cut of Bromegrass from Selected Treatments from 1973 to 1977 Inclusive.	94
78	Nickel Concentrations in Corn Stover from Elora and Cambridge, 1973 to 1977 Inclusive.	95
79	Lead Concentration in First Cut (June 8). Bromegrass. Elora, 1977.	96
80	Zinc Concentration in First Cut (June 8). Bromegrass. Elora, 1977.	97
81	Zinc Concentration in Corn Stover. Elora, 1977.	98
82	Zinc Concentration in Corn Stover. Cambridge, 1977.	99
83	Zinc Concentrations in First Cut of Bromegrass from Selected Treatments from 1973 to 1977 Inclusive.	100
84	Zinc Concentrations in Corn Stover from Elora and Cambridge, 1973 to 1977 Inclusive.	101
85	Concentrations of Antimony, Cobalt, Mercury, Molybdenum and Selenium in First Cut of Bromegrass from Selected Treatments (June 8, 1977).	102

LIST OF TABLES (CONT'D)

Table		Page
86	Antimony, Cobalt, Mercury, Molybdenum and Selenium Concentrations of Corn Grain and Stover from Selected Treatments, 1977.	103
87	NTA-Extractable Cadmium, Copper, Nickel and Zinc from Surface Soil (0-6 in), November 1977.	104
88	Crop Management Schedule, Greenhouse Experiment, 1977.	111
89	Chemical Analysis of Sludges Used in Greenhouse for 9th Crop of Ryegrass (fluid basis).	112
90	Chemical Analysis of Sludges Used in Greenhouse for 10th Crop of Ryegrass (fluid basis).	113
91	Chemical Analysis of Sludges Used in Greenhouse for 11th Crop of Ryegrass (fluid basis).	114
92	Total Amounts of Nutrients and Metals Added in 9th Application of Sludge at 200 kg N/ha to Greenhouse Experiment.	115
93	Total Amounts of Nutrients and Metals Added in 10th Application of Sludge at 200 kg N/ha to Greenhouse Experiment.	116
94	Total Amounts of Nutrients and Metals Added in 11th Application of Sludge at 200 kg N/ha to Greenhouse Experiment.	117
95	Total Amounts of Nutrients and Metals Added in Sludge at 200 kg N/ha Per Application to Soil in Greenhouse Experiment in 9 Crops.	118
96	Total Amounts of Nutrients and Metals Added in Sludge at 200 kg N/ha Per Application to Soil in Greenhouse Experiment in 10 Crops.	119
97	Total Amounts of Nutrients and Metals Added in Sludge at 200 kg N/ha Per Application to Soil in Greenhouse Experiment in 11 Crops.	120
98	Concentration of Nutrients and Heavy Metals in Leachate from Selected Treatments Before the 9th Crop of Ryegrass.	121
99	Concentration of Nutrients and Heavy Metals in Leachate from Selected Treatments Before the 11th Crop of Ryegrass.	123

LIST OF TABLES (CONT'D)

Table		Page
100	Total Amounts of Nutrients and Heavy Metals Leached from Selected Treatments Before the 9th Crop of Ryegrass.	125
101	Total Amounts of Nutrients and Heavy Metals Leached from Selected Treatments Before the 11th Crop of Ryegrass.	127
102	Dry Matter Yield of 9th Crop of Ryegrass After Addition of Sewage Sludge Before each of the First Five Crops.	129
103	Dry Matter Yield of 10th Crop of Ryegrass After Addition of Sewage Sludge Before each of the First Five Crops.	130
104	Dry Matter Yield of 11th Crop of Ryegrass After Addition of Sewage Sludge Before each of the First Five Crops.	131
105	Nitrogen Concentration in 9th Crop of Ryegrass After Addition of Sewage Sludge Before each of the First Five Crops.	132
106	Nitrogen Concentration in 10th Crop of Ryegrass After Addition of Sewage Sludge Before each of the First Five Crops.	133
107	Nitrogen Concentration in 11th Crop of Ryegrass After Addition of Sewage Sludge Before each of the First Five Crops.	134
108	pH Values of Soil After the 10th Crop of Ryegrass.	135
109	Phosphorus Concentration in 10th Crop of Ryegrass After Addition of Sewage Sludge Before each of the First Five Crops.	136
110	Potassium Concentration in 9th Crop of Ryegrass After Addition of Sewage Sludge Before each of the First Five Crops.	137
111	Potassium Concentration in 10th Crop of Ryegrass After Addition of Sewage Sludge Before each of the First Five Crops.	138
112	Calcium Concentration in 10th Crop of Ryegrass After Addition of Sewage Sludge Before each of the First Five Crops.	139
113	Magnesium Concentration in 9th Crop of Ryegrass After Addition of Sewage Sludge Before each of the First Five Crops.	140

LIST OF TABLES (CONT'D)

Table		Page
114	Manganese Concentration in 9th Crop of Ryegrass After Addition of Sewage Sludge Before each of the First Five Crops.	141
115	Manganese Concentration in 11th Crop of Ryegrass After Addition of Sewage Sludge Before each of the First Five Crops.	142
116	Iron Concentration in 9th Crop of Ryegrass After Addition of Sewage Sludge Before each of the First Five Crops.	143
117	Iron Concentration in 10th Crop of Ryegrass After Addition of Sewage Sludge Before each of the First Five Crops.	144
118	Boron Concentration in 9th Crop of Ryegrass After Addition of Sewage Sludge Before each of the First Five Crops.	145
119	Boron Concentration in 11th Crop of Ryegrass After Addition of Sewage sludge Before each of the First Five Crops.	146
120	Cadmium Concentration in 9th Crop of Ryegrass After Addition of Sewage Sludge Before each of the First Five Crops.	147
121	Cadmium Concentration in 10th Crop of Ryegrass After Addition of Sewage Sludge Before each of the First Five Crops.	148
122	Cadmium Concentration in 11th Crop of Ryegrass After Addition of Sewage Sludge Before each of the First Five Crops.	149
123	Cadmium Concentration in Crops 1 to 11 of Ryegrass Receiving Sewage Sludges from Guelph and North Toronto Before each Crop.	150
124	Chromium Concentration in 9th Crop of Ryegrass After Addition of Sewage Sludge Before each of the First Five Crops.	151
125	Copper Concentration in 9th Crop of Ryegrass After Addition of Sewage Sludge Before each of the First Five Crops.	152

LIST OF TABLES (CONT'D)

Table | Page

126 Copper Concentration in 10th Crop of Ryegrass After Addition of Sewage Sludge Before each of the First Five Crops. 153

127 Copper Concentration in 11th Crop of Ryegrass After Addition of Sewage Sludge Before each of the First Five Crops. 154

128 Copper Concentration in Crops 1 to 11 of Ryegrass Receiving Sewage Sludges from Sarnia and North Toronto Before each Crop. 155

129 Lead Concentration in 10th Crop of Ryegrass After Addition of Sewage Sludge Before each of the First Five Crops. 156

130 Lead Concentration in 11th Crop of Ryegrass After Addition of Sewage Sludge Before each of the First Five Crops. 157

131 Nickel Concentration in 9th Crop of Ryegrass After Addition of Sewage Sludge Before each of the First Five Crops. 158

132 Nickel Concentration in 10th Crop of Ryegrass After Addition of Sewage Sludge Before each of the First Five Crops. 159

133 Nickel Concentration in 11th Crop of Ryegrass After Addition of Sewage Sludge Before each of the First Five Crops. 160

134 Nickel Concentration in Crops 1 to 11 of Ryegrass Receiving Sewage Sludges from Midland and North Toronto Before each Crop. 161

135 Zinc Concentration in 9th Crop of Ryegrass After Addition of Sewage Sludge Before each of the First Five Crops. 162

136 Zinc Concentration in 10th Crop of Ryegrass After Addition of Sewage Sludge Before each of the First Five Crops. 163

137 Zinc Concentration in 11th Crop of Ryegrass After Addition of Sewage Sludge Before each of the First Five Crops. 164

LIST OF TABLES (CONT'D)

Table		Page
138	Zinc Concentration in Crops 1 to 11 of Ryegrass Receiving Sewage Sludges from Sarnia and North Toronto Before each Crop.	165
139	Antimony Concentration in Ryegrass from Selected Treatments of Greenhouse Experiment.	166
140	Cobalt Concentration in Ryegrass from Selected Treatments of Greenhouse Experiment.	167
141	Mercury Concentration in Ryegrass from Selected Treatments of Greenhouse Experiment.	168
142	Molybdenum Concentration in Ryegrass from Selected Treatments of Greenhouse Experiment.	169
143	Selenium Concentration in Ryegrass from Selected Treatments of Greenhouse Experiment.	170

1. INTRODUCTION

This volume covers work done by the Department of Land Resource Science at the University of Guelph on land disposal of sewage sludge. The work was financed by Environment Canada and the Ontario Ministry of the Environment under project no. 72-5-17 of the Canada-Ontario Agreement on Great Lakes Water Quality and covers the period from April 1, 1977 to March 31, 1978. Previous work under this project has been published as Land Disposal of Sewage Sludge, Research Reports No. 16, 24, 35, 60 and 73 (designated Volumes I, II, III, IV and V, respectively).

The research program proceeded on schedule during 1977/78. Early May was drier than normal allowing good progress at sludge application in the field. This advantage was offset by difficulty in getting sludge hauled when required, with the result that seeding was late on the Cambridge corn experiment. The summer had few periods of above-average temperature, the heat unit accumulation was slightly higher than the long-term average, and moisture was well distributed. The bromegrass and corn crops suffered little from drought even on the Caledon loamy sand at Cambridge.

In the Bromegrass trial only the first cut was analyzed chemically as in 1976.

As the work continues it becomes increasingly interesting to study the changes or lack of them in metal and nutrient uptake from year to year and crop to crop. In a number of cases the patterns emerging were unexpected.

2. OBJECTIVES

The objective of this research is to determine the maximum rates of sewage sludge application that can be used on agricultural soil without contaminating subsurface water with nitrate nitrogen and surface waters with elements pathogenic to humans and animals, and without reducing the yield or quality of the crops produced.

3. RUNOFF

3.1 Objectives

This section of the sludge project was designed to determine rates of sewage sludge which may be safely applied to certain slopes at specified times of the year.

3.2 Experimental

3.2.1 Design

Runoff was measured at the Elora Research Station on an imperfect to poorly-drained silty clay loam soil with systematic tile drains. Field plots, 0.025 acre (0.01 hectare) on 2% and 6% slopes with suitable edging and runoff collection devices were installed in the fall of 1972. Fluid digested sewage sludge resulting from iron treatment of sewage for phosphorus removal at the North Toronto sewage treatment plant was applied to separate plots each November, January and April.

Rates of application, based on the nitrogen content of the sludge, were 178 lb N/ac (200 kg N/ha) and 712 lb N/ac (800 kg N/ha) on the 2% slope and 178 lb N/ac (200 kg N/ha) on the 6% slope. On each slope the treatment without sludge received 100 lb N/ac (112 kg N/ha) as NH_4NO_3 in the spring. There were two replicates of each treatment.

Runoff from each plot was collected in a tank. After each runoff event, the volumes of runoff collected were measured, samples taken and the tanks emptied. Following the 1976 winter period, the 2% slope treatments were discontinued but the study continued on the 6% slope.

The field work ceased at the end of November 1977 after five years of observations.

3.2.2 Water analysis

Soluble nitrogen and phosphorus in the water samples were determined directly by an automated procedure after passing through a 0.45 μ filter. Total nitrogen and phosphorus in the unfiltered water samples were determined by an automated procedure after digestion with H_2SO_4-H_2O_2. Metal losses in summer 1977 were similar to those in 1976 with the exception of soluble lead which was higher in 1976 and acid-extractable copper and zinc which were higher in 1977.

Acid-extractable metals were brought into solution by digesting unfiltered water samples with aqua regia. Soluble metals were determined on the filtrate after the water samples were passed through a 0.45 μ filter. Both acid-extractable and soluble metals (Cd, Cu, Ni, Pb and Zn) were determined by atomic absorption with a Varian-Techtron AA6 spectrophotometer and using a CRA 90 furnace when necessary.

Mercury content of filtered (0.45 μ) water samples was determined by flameless atomic absorption after oxidation of the organic mercurials with potassium permanganate and potassium persulphate. Sediment collected on the filters was digested with aqua regia at 60°C before mercury determination by flameless atomic absorption.

3.3 Results and Discussion

3.3.1 Crop yield

Germination of corn was normal and the stand thinned to 20,000 plants per acre on June 15. The grain was harvested on October 11 and the yields are presented in Table 1. There was little difference in yield between different times of sludge application. Yield for all treatments was higher than the yields for 1976, 1974 or 1973 but was lower than 1975.

3.3.2 Precipitation and runoff losses

Total precipitation of the two runoff periods ending November 19, 1977 (Tables 2, 3 and 4) was 75.04 cm. Five runoff events occurred following the winter application of sludge (January 21) (Table 3) and two events occurred following the spring application of sludge (Table 4). The winter events were mainly due to snow melt during a warm spell in early March.

The losses of total and soluble nitrogen and phosphorus are shown in Table 5 for the winter period and for the summer period in Table 6. Losses for the winter period were considerably higher than in 1976. This was due to the greater number of events, five in 1977 to one in 1976. The summer period losses were also slightly higher than in 1976.

The soluble and the acid-extractable metals (winter and summer periods) are shown in Tables 7 and 8. Metal losses in the winter period were much higher than in 1976, especially lead, zinc and copper.

An estimate of the amount of organic material present in runoff water (winter and summer periods) is given by the value of the chemical oxygen demand (Table 9). Organic matter losses were much greater in 1977 and 1976.

3.4 Conclusions

Runoff losses continued to be small with generally less than two kilograms N or one kilogram P per hectare lost in one year.

The absence of a winter thaw increased the amount of runoff losses in the spring of 1977.

Sludge application at the 200 kg N/ha rate did not appear to increase either the metal loss, chemical oxygen demand, or the nitrogen and phosphorus loss, as compared to the check plots.

Sludge application in winter did not increase nutrient losses. However, it seems advisable to use the more level land, to avoid spreading sludge when there is ice on the soil surface, and to use low application rates.

3.5 Five-Year Summary

The amount and intensity of rainfall directly affects runoff, as does the amount of snow cover in winter. In this study, the fall rains caused runoff only on occasions where the sludge was applied immediately ahead of a rainfall (1973, 1974). If sludge application could have been delayed until after the rain, runoff would have been avoided. Furthermore, if sludge was allowed to dry on the soil surface, subsequent infiltration of rain was increased compared to that through a moist sludge layer, and nutrients were less likely to be carried by any runoff. The summer rains occurred with sufficient intensities in 1973, 1974 and 1975 to produce runoff before the corn had sufficient foliage to protect the soil. Losses later in the season were less. Average losses for the summer events in the years with runoff (1973, 1974) were 4-8 ton/ac for 6% the slope, and 1-2 ton/ac for the 2% slope.

Winters could be divided into two categories: those with and those without a January thaw. The winters of 1976 and 1977 were without this thaw period; temperatures remained generally below freezing, the snow depth was about 3 feet, and the underlying soil was not frozen. This facilitated infiltration of meltwater and reduced runoff. The other winters had a January thaw during which the snow depth was decreased, and subsequent to which the underlying soil froze to a minimum depth of one foot. This reduced infiltration and increased runoff from subsequent precipitation.

Corn yields were generally similar between seasons during the study period. The highest yields occurred in 1975 and coincided with more favourable rainfall during the growing season.

Generally the concentrations of the metals (Zn, Cu, Pb, Cd, Ni and Hg) analyzed in the runoff waters were low, and in many instances near the detection limits. The greater concentrations were usually observed for the summer periods, due mainly to greater sediment losses. While the amount of metal loss compared to the amount applied was low during the course of this experiment, and did not exceed acceptable limits, marked increase in rate of application or steepness of slope might create problems.

In general, the study indicates that:

a) Runoff losses can be restricted to acceptable limits by the use of good management practices, e.g. suitable rates and times of application relative to topography.
b) Sludge should not be applied when there are prospects of rain during or immediately following application.
c) Winter application of sludge should be avoided when a prolonged warm spell is forecast.

TABLE 1. YIELD OF CORN GRAIN* IN 1973, 1974, 1975, 1976 and 1977.

Slope and Treatment		1973	1974	1975	1976	1977
				lb/ac (kg/ha)		
6% slope						
200 kg N	Fall	4390 (4920)	4600 (5150)	7210 (8070)	5790 (6490)	5419 (6075)
	Winter	4010 (4490)	4450 (4990)	6690 (7490)	5320 (5970)	5969 (6692)
	Spring	4200 (4700)	4510 (5050)	6740 (7540)	5500 (6180)	6232 (6987)
	Check	4190 (4690)	4640 (5200)	6800 (7620)	6070 (6810)	6262 (7020)
2% slope						
200 kg N	Fall	4480 (5020)	6280 (7040)	8040 (9000)		
	Winter	3610 (4040)	6090 (6820)	7860 (8800)		
	Spring	4390 (4920)	5250 (5880)	8090 (9060)		
800 kg N	Fall	6030 (6750)	5070 (5670)	7860 (8800)		
	Winter	5760 (6450)	4810 (5390)	7970 (8930)		
	Spring	5690 (6370)	5580 (6250)	8090 (9060)		
	Check	4270 (4780)	4900 (5490)	7629 (8530)		

* 15% moisture

TABLE 2. MONTHLY AND CUMULATIVE PRECIPITATION FOR THE ELORA RESEARCH STATION, 1977.

Month	January 1977-December 1977				30-year average			
	Monthly total		Cumulative total		Monthly total		Cumulative total	
	in	(cm)	in	(cm)	in	(cm)	in	(cm)
January	1.65	4.19	1.65	4.19	2.79	7.08	2.79	7.08
February	1.73	4.39	3.38	8.59	2.24	5.69	5.03	12.77
March	2.72	6.91	6.10	15.49	2.48	6.30	7.51	19.07
April	1.57	3.99	7.67	19.48	2.70	6.86	10.21	25.93
May	1.72	4.37	9.39	23.85	3.10	7.87	13.31	33.80
June	2.33	5.92	11.72	29.77	3.00	7.62	16.31	41.42
July	3.43	8.71	15.15	38.48	3.10	7.87	19.41	49.29
August	4.69	11.91	19.84	50.39	3.10	7.87	22.51	57.16
September	6.12	15.54	25.96	65.94	3.00	7.62	25.51	64.78
October	2.59	6.58	28.55	72.52	2.79	7.08	28.30	71.85
November	3.45	8.76	32.00	81.28	2.70	6.86	31.00	78.72
December	2.71	6.88	34.71	88.16	2.79	7.08	33.79	85.80

TABLE 3. RAINFALL IN WINTER PERIOD, ELORA (January 21, 1977 to May 12, 1977)

Day of Month	Jan. in	Jan. cm	Feb. in	Feb. cm	Mar. in	Mar. cm	Apr. in	Apr. cm	May in	May cm
1			0.08	0.20			0.02	0.05	0.08	0.20
2			0.04	0.10			0.32	0.81		
3			0.03	0.08	0.06	0.15				
4			0.02	0.05	0.48	1.22	0.51	1.30	T	T
5							0.04	0.10	T	T
6					0.04	0.10	0.01	0.03		
7							0.02	0.05		
8			0.04	0.10	—	—				
9			0.06	0.15						
10					—	—				
11					—	—				
12			0.25	0.63	$\overline{0.93}$	$\overline{2.36}$				
13			0.05	0.13			0.02	0.05		
14			0.01	0.03						
15					$\overline{0.13}$	$\overline{0.33}$				
16										
17					0.01	0.03	T	T		
18			0.01	0.03	0.10	0.25	0.01	0.03		
19							0.03	0.08		
20					0.22	0.56	T	T		
21	$\boxed{0.02}$	$\boxed{0.05}$					0.09	0.23		
22			0.04	0.10	0.04	0.10	0.17	0.43		
23	0.01	0.03	0.10	0.25	0.04	0.10	0.33	0.84		
24	0.05	0.13	0.51	1.30						
25	0.03	0.08	0.01	0.03						
26	0.14	0.36	0.09	0.23			T	T		
27	0.10	0.25	0.38	0.97	0.13	0.33				
28	0.27	0.69	0.01	0.03	0.49	1.24				
29										
30	0.02	0.05			0.05	0.13				
31	0.03	0.08								
Monthly Total	0.67	1.72	1.73	4.39	2.72	6.91	1.57	3.99	0.08	0.20
Cumulative Total	0.67	1.72	2.40	6.11	5.12	13.00	6.69	16.99	5.77	17.19

☐ Denotes a date of sludge application

—— Denotes a date on which a runoff occurred

T Denotes trace (<0.01 in)

TABLE 4. RAINFALL IN SUMMER PERIOD, ELORA (May 13, 1977 to November 20, 1977)

Day of Month	May in	May cm	June in	June cm	July in	July cm	Aug. in	Aug. cm
1			0.21	0.53				
2			T	T			0.02	0.05
3					T	T	0.02	0.05
4					T	T	0.16	0.41
5			0.25	0.63	0.74	1.88	0.75	1.91
6			0.24	0.61	1.39	3.53		
7					$\underline{0.40}$	$\underline{1.02}$	0.41	1.04
8							0.34	0.86
9							0.10	0.25
10							T	T
11			T	T	0.02	0.05	0.06	0.15
12					T	T		
13	$\boxed{0.02}$	$\boxed{0.05}$					0.15	0.38
14								
15								
16			0.31	0.79			1.33	3.38
17	0.44	1.12	0.15	0.38	T	T	$\underline{0.01}$	$\underline{0.03}$
18	T	T	0.12	0.30				
19							0.02	0.05
20			T	T				
21							0.17	0.43
22								
23							0.42	1.07
24	0.70	1.78	0.23	0.58	0.11	0.28		
25			T	T				
26								
27								
28	0.11	0.28	0.77	1.96			0.02	0.05
29	T	T	T	T	0.37	0.94	0.46	1.17
30			0.05	0.13	0.03	0.08		
31	0.37	0.94			0.37	0.94	0.25	0.63
Monthly Total	1.64	4.16	2.33	5.92	3.43	8.71	4.69	11.91
Cumulative Total	1.64	4.16	3.97	10.08	7.40	18.80	12.09	30.71

☐ Denotes a date of sludge application

___ Denotes a date on which a runoff occurred

T Denotes trace (<0.01 in)

TABLE 4. (CONT'D)

Day of Month	Sept.		Oct.		Nov.	
	in	cm	in	cm	in	cm
1	0.25	0.64	0.83	2.11		
2			T	T		
3					0.04	0.10
4	0.03	0.08				
5			0.01	0.03		
6	T	T			0.01	0.03
7			0.17	0.43	0.27	0.69
8			1.12	2.84	0.01	0.02
9	T	T	0.03	0.08	0.25	0.63
10	T	T			0.42	1.07
11			0.12	0.30	0.06	0.15
12	0.35	0.89	0.01	0.03	T	T
13	0.45	1.41			0.01	0.02
14						
15	0.08	0.20	0.28	0.71	0.09	0.22
16	0.71	0.80			0.30	0.76
17	0.34	0.86	T	T	0.36	0.92
18	0.06	0.15			0.14	0.36
19	0.87	2.21	T	T	0.01	0.02
20	0.07	0.18	T	T		
21			0.01	0.03		
22	0.05	0.13				
23			0.01	0.03		
24	1.41	3.58	T	T		
25	0.78	1.98	0.01	0.03		
26	0.20	0.51				
27	0.04	0.10				
28	0.02	0.05				
29	T	T				
30	0.41	1.04				
31			T	T		
Monthly Total	6.12	15.54	2.60	6.60	1.97	5.00
Cumulative Total	18.21	46.25	20.81	52.85	22.78	57.85

☐ Denotes a date of sludge application

—— Denotes date on which a runoff occurred

T Denotes trace (<0.01 in)

TABLE 5. RUNOFF LOSSES IN WINTER PERIOD (January 21 - May 12, 1977), TOTAL AND SOLUBLE NITROGEN AND PHOSPHORUS

Slope and Treatment		Runoff		Nitrogen		Phosphorus	
		in	(cm)	lb/ac	(kg/ha)	lb/ac	(kg/ha)
6% Slope				Total			
200 kg N	Fall	3.51	8.92	1.55	(1.74)	0.55	(0.62)
	Winter	2.01	5.11	1.29	(1.45)	0.37	(0.41)
	Spring	2.81	7.14	1.14	(1.28)	0.29	(0.33)
	Check	2.66	6.76	0.90	(1.01)	0.37	(0.42)
6% Slope				Soluble Fraction			
200 kg N	Fall	3.51	8.92	0.69	(0.77)	0.37	(0.41)
	Winter	2.01	5.11	0.48	(0.54)	0.22	(0.25)
	Spring	2.81	7.14	0.36	(0.40)	0.20	(0.22)
	Check	2.66	6.76	0.29	(0.32)	0.13	(0.15)

TABLE 6. RUNOFF LOSSES IN SUMMER PERIOD (May 13 - November 19, 1977), TOTAL AND SOLUBLE NITROGEN AND PHOSPHORUS

Slope and Treatment		Runoff		Nitorgen		Phosphorus	
		in	(cm)	lb/ac	(kg/ha)	lb/ac	(kg/ha)
6% Slope				Total			
200 kg N	Fall	0.77	1.96	0.78	(0.88)	0.33	(0.37)
	Winter	0.57	1.45	0.56	(0.63)	0.27	(0.30)
	Spring	0.79	2.01	0.55	(0.62)	0.23	(0.26)
	Check	1.05	2.67	3.20	(3.59)	1.04	(1.17)
6% Slope				Soluble Fraction			
200 kg N	Fall	0.77	1.96	0.03	(0.03)	0.05	(0.06)
	Winter	0.57	1.45	0.03	(0.03)	0.04	(0.04)
	Spring	0.79	2.01	0.05	(0.06)	0.04	(0.04)
	Check	1.05	2.67	0.09	(0.10)	0.06	(0.07)

TABLE 7. SOLUBLE AND ACID-EXTRACTABLE METALS IN RUNOFF - WINTER 1977.

Slope and Treatment		Cd	Cu	Hg	Ni	Pb	Zn
				lb/ac x 10^{-3} (kg/ha x 10^{-3})			
				Soluble fraction			
6% Slope							
200 kg N	Fall	1.03(1.15)	5.54(6.20)	1.50(1.68)	<19.80(<22.18)	22.96(25.72)	26.92(30.15)
	Winter	0.54(0.60)	5.35(5.99)	0.86(0.96)	<11.29(<12.64)	96.18(107.72)	76.76(85.97)
	Spring	1.27(1.42)	3.81(4.27)	1.21(1.36)	<15.86(<17.76)	7.61(8.52)	22.84(25.58)
	Check	1.00(1.12)	3.53(3.95)	1.12(1.25)	<14.70(<16.46)	5.88(6.59)	18.82(21.08)
				Acid-extractable fraction			
6% Slope							
200 kg N	Fall	6.73(7.54)	69.69(78.05)	1.90(2.13)*	<19.80(<22.18)	380.90(426.61)	277.95(311.30)
	Winter	3.48(3.90)	48.77(54.62)	1.08(1.21)	<11.29(<12.64)	166.62(186.61)	137.72(154.25)
	Spring	4.57(5.12)	25.37(28.41)	1.52(1.70)	<15.86(<17.76)	100.23(112.26)	352.07(394.32)
	Check	3.35(3.75)	45.87(51.37)	1.29(1.44)	<14.70(<16.46)	90.57(101.44)	299.93(335.92)

* Sum of Hg in filtered (0.45μ) water samples and in sediments

TABLE 8. SOLUBLE AND ACID-EXTRACTABLE METALS IN RUNOFF - SUMMER 1977.

Slope and Treatment		Cd	Cu	Hg	Ni	Pb	Zn
				lb/ac x 10^{-3} (kg/ha x 10^{-3})			
				Soluble fraction			
6% Slope							
200 kg N	Fall	0.17(0.19)	1.74(1.95)	0.33(0.37)	<4.35(<4.87)	1.39(1.56)	5.92(6.63)
	Winter	0.18(0.20)	1.52(1.70)	0.24(0.27)	<3.17(<3.55)	0.89(1.00)	5.70(6.38)
	Spring	0.57(0.64)	1.07(1.20)	0.34(0.38)	<4.46(<5.00)	1.43(1.60)	5.71(6.40)
	Check	0.28(0.31)	2.37(2.65)	0.45(0.50)	<5.92(<6.63)	1.66(1.86)	7.58(8.49)
				Acid-extractable fraction			
6% Slope							
200 kg N	Fall	1.11(1.24)	30.10(33.71)	0.47(0.53)*	12.88(14.43)	66.47(74.45)	119.20(133.50)
	Winter	0.76(0.85)	25.09(28.10)	0.34(0.38)	9.38(10.51)	25.21(28.24)	69.56(77.91)
	Spring	0.59(0.66)	11.24(12.59)	0.48(0.54)	<4.46(<5.00)	21.41(23.98)	54.59(61.14)
	Check	1.71(1.92)	58.73(65.78)	0.64(0.72)	31.97(35.81)	116.99(131.03)	191.59(214.58)

* Sum of Hg in filtered (0.45μ) water samples and in sediments.

TABLE 9. COD* IN RUNOFF WATER FOR WINTER AND SUMMER PERIODS, 1977.

Slope and Treatment		Winter		Summer	
		lb/ac	(kg/ha)	lb/ac	(kg/ha)
6% Slope					
200 kg N	Fall	23.5	(26.4)	24.3	(27.2)
	Winter	20.3	(22.7)	19.1	(21.4)
	Spring	18.9	(21.1)	14.7	(16.4)
	Check	25.6	(28.8)	70.0	(78.5)

* chemical oxygen demand

4. FIELD RATE AND SOURCE EXPERIMENTS

4.1 Objectives

The objective of the field rate and source experiments was to determine the rate of three chemically-treated sludges which may be safely used on typical Ontario soils without adversely affecting crop yields or nitrate and heavy metal content.

4.2 Materials and Methods

4.2.1 General

Experiments have been in progress since 1973 on two soils, a Conestoga loam at the Elora Research Station and a Caledon loamy sand at the Cambridge (Hespeler) Research Station. At the Elora Research Station one experiment is in progress on a Conestoga loam with corn (*Zea mays* L.) as the crop and one with bromegrass (*Bromis inermis Leyess*). Only corn is being grown on the Caledon loamy sand at the Cambridge site.

The sources of nitrogen used in these trials were ammonium nitrate and combined waste activated primary and secondary fluid digested sewage sludges resulting from calcium hydroxide, aluminum sulphate and ferric chloride treatment of sewage for phosphorus removal. Chemical composition of sludges used in 1977 is presented in Table 10, and the amounts of various constituents applied in the sludges are presented in Tables 11 to 16.

The rates of nitrogen application each year from ammonium nitrate were: 0, 89, 178 and 356 lb N/ac (0, 100, 200 and 400 kg N/ha). The rates from each of the three sewage sludges were: 178, 356, 712 and 1424 lb N/ac (200, 400, 800 and 1600 kg N/ha).

There were four nitrogen sources, four rates, and three replications resulting in a total of 48 plots for each trial. The corn plot size was 15' x 25' (4.57 x 7.62 m) and the bromegrass plot size was 8' x 20' (2.44 x 6.09 m).

4.2.2 Bromegrass, Elora

The bromegrass trial has been in progress for five years. It was laid out on an established stand of bromegrass on the Elora Research Station on Conestoga loam in the spring of 1973. Potassium chloride supplying 50 lb K_2O/ac (47 kg K/ha) was broadcast on all plots in the spring of 1973 and supplied 97 lb of K_2O/ac (90 kg k/ha) in the springs of 1974, 1975, 1976 and 1977. Eighty-three lb P_2O_5/ac (40 kg P/ha) as 46% superphosphate was broadcast on the plots which did not receive sludge in the spring of 1973, 80 lb P_2O_5/ac (39 kg P/ha) in the spring of 1974, and 83 lb P_2O_5/ac (40 kg P/ha) in the springs of 1975, 1976 and 1977. Annual nitrogen rates for the bromegrass were divided into three equal applications for both the ammonium nitrate and sewage sludges. The dates of nitrogen and sludge application to grass are presented, along with harvest dates, in Table 17 and the amounts of nutrients and metals added in the sludges are presented in Tables 11 and 12. To reduce costs only the first cut of bromegrass was analyzed chemically and only selected treatments were analyzed for Co, Mo, Se, Sb and Hg.

4.2.3 Corn, Elora and Cambridge

The two corn trials have been in progress for five years. In the fall of 1972 an old stand of bromegrass was plowed under at the Elora Research Station and an oat cover crop was plowed under at the Cambridge site to establish these trials. Field operations in 1977 are listed in Table 18, the chemical composition of the sludges used is described in Table 10, and the amounts of nutrients and metals added in the sludges are presented in Tables 13, 14, 15 and 16.

To reduce costs, and because corn grain samples showed few differences in chemical composition in previous years, corn grain samples from only two ammonium nitrate rates and the highest rates of sewage sludges were analyzed chemically. Also, only selected treatments of the corn stover were analyzed for Co, Mo, Se, Sb and Hg.

4.3 Results and Discussion

4.3.1 The 1977 season

In 1977, May was drier than normal allowing a good start on field operations. Sludge application was delayed, however, because the contractor for sludge hauling ran into mechanical problems. Emergence of corn and final stands were adequate in spite of a dry spell during germination and emergence. The moisture supply was better than usual in

1977 with few prolonged dry periods. The Cambridge corn experiment in particular suffered less than usual from dry weather.

In general, only the 1977 data are discussed in this report as the 1973, 1974, 1975 and 1976 results were discussed in previous reports. With the exception of crop yields, data for different treatments are presented only where there were significant treatment effects.

Bromegrass yields for the three cuttings in 1977 are presented in Tables 19, 20 and 21 and the total annual yields for 1977, 1976, 1975 and 1974 in Tables 22, 23, 24 and 25. In 1977, as in previous years, the first cutting made up a very large portion of the total bromegrass yield for the season (approximately 60%). Yields were increased by sludge application up to 400 kg N/ha and were not significantly different at rates in excess of 400 kg N/ha. Ammonium nitrate increased yield significantly at up to 200 kg N/ha; 400 kg N/ha increased yield slightly but not significantly over 200 kg N/ha. The three sludge sources produced similar yields. The average yields with sludge increased each year from 1974 through 1977. Yields with NH_4NO_3 were also high in 1977, probably due to the plentiful moisture supply during the growing season.

Corn stover yields at Elora and Cambridge were not affected by treatment in 1977 (Tables 26 and 27).

Corn grain yields were increased significantly over yields without nitrogen by application of sludge at both Elora and Cambridge, and by ammonium nitrate at Elora. Yields were not increased significantly by sludge rates supplying more than 200 kg N/ha (Tables 28 and 29).

Nitrogen concentration in the bromegrass (Table 30), and in the corn stover (Tables 31 and 32) were increased by ammonium nitrate or sludge application. The higher yields of bromegrass with sludge than with NH_4NO_3 (Table 22) do not appear to have been due to a lack of nitrogen with NH_4NO_3 treatments. The calcium sludge produced slightly lower nitrogen concentrations in the bromegrass than did the other sludges (Table 30) but not in corn stover in the other two trials. There was little or no effect of treatment on N concentration in the corn grain (Table 33).

Nitrate-N concentration in the bromegrass and corn stover from Cambridge increased with rate of nitrogen from ammonium nitrate and from sludge (Tables 34 and 35). Nitrate concentrations were lower with the calcium than with iron or aluminum sludges.

Phosphorus concentration in bromegrass was higher with the calcium sludge than with the other sludges or ammonium nitrate (Table 36). In the corn stover and corn grain phosphorus concentration was little affected by treatment (Tables 37, 38 and 33).

Soil phosphorus extracted by sodium bicarbonate was markedly increased by sludge application in all three experiments (Tables 39, 40 and 41). This effect was much more marked with the calcium sludge than with either the aluminum or the iron sludge.

Potassium concentration in bromegrass was increased by the high rate of aluminum sludge but not by the other sludges (Table 44). Potassium concentration in corn stover at Elora and Cambridge increased slightly with increased rate of sludge application (Tables 43 and 44). Corn grain potassium was not significantly affected by treatment (Table 33).

Soil potassium extracted with ammonium acetate was not greatly affected by treatment (Tables 45 and 46).

Calcium concentration in the bromegrass (Table 46) increased with rate of application of sludge.

Soil calcium extracted with ammonium acetate was increased by the calcium sludge (Tables 48, 49 and 50).

Calcium sludge application increased soil pH in all three trials (Tables 51, 52 and 53), and the iron sludge decreased soil pH significantly on all three sites. Ammonium nitrate and aluminum sludge showed a trend toward lower pH with increasing rates of application but in most cases this was not significant.

Magnesium concentration in bromegrass was increased by nitrogen application from ammonium nitrate or from sludge (Table 54) but only ammonium nitrate increased the magnesium concentration in the corn stover (Table 55).

Soil magnesium extracted with ammonium acetate from the bromegrass trial increased with the highest rate of ammonium nitrate and decreased with the highest rate of aluminum sludge (Table 56). In the Elora corn trial soil magnesium decreased with the calcium sludge but increased with the high rate of iron sludge (Table 57).

Manganese concentration in bromegrass was reduced by sludge application (Table 58). Higher rates of calcium and aluminum sludge reduced manganese concentrations more than did low rates. Manganese concentration in corn stover from Elora was increased by the high rate of ammonium nitrate (Table 59).

Iron concentrations in bromegrass and corn were not affected by treatment.

Boron concentration in the bromegrass was little affected by nitrogen from ammonium nitrate or from sewage sludge (Table 60). Corn stover boron concentrations were not affected by treatment.

Cadmium concentrations in bromegrass and in corn stover at both sites was increased by high rates of aluminum and iron sludges (Tables 61, 62 and 63). There was a tendency for ammonium nitrate to increase plant cadmium at all three sites and this was significant (by F test) in the corn stover at both sites. Cadmium concentration in the corn grain at Cambridge may have been increased slightly by the high rate of aluminum sludge (Table 64).

Cadmium concentrations in bromegrass and corn stover for the period 1973 to 1977 from selected treatments are presented in Tables 65 and 66. The values were rather variable from year to year but there appears to be some increase in cadmium concentration in the corn stover over the five-year period with the aluminum sludge.

Chromium concentration in the bromegrass was little affected by treatment (Table 67). Chromium concentration in the corn stover from Cambridge tended to be higher with the high rates of aluminum sludge than with other treatments (Table 68).

Copper concentrations in the bromegrass and in corn stover from both experiments was increased by ammonium nitrate or sewage sludge (Tables 69, 70 and 71). The copper concentration in the bromegrass was higher with higher rates of sludge than with the highest rate of ammonium nitrate. Copper concentration in corn grain was somewhat variable, but ammonium nitrate at the highest rate appeared to increase copper in the grain from Elora (Table 64).

Copper concentrations in bromegrass and in corn stover from selected treatments for the period of 1973 to 1977 are presented in

Tables 72 and 73. There does not appear to be an increase in copper concentration from year to year in the three trials even with the highest rate of sludge application.

Nickel concentration in bromegrass increased markedly with the calcium sludge and to a lesser extent with the high rate of aluminum sludge (Table 74). Nickel concentrations in the corn stover from Elora and Cambridge were also increased by the calcium sludge, but the effect of sludge rate was variable (Tables 75 and 76). The highest rate of the calcium sludge also increased nickel concentration in the corn grain (Table 64). The use of a calcium sludge high in nickel in 1976 and 1977 caused a marked increase in nickel concentration in bromegrass and a tendency toward increased concentration in corn in 1977 (Tables 77 and 78).

Lead concentration in bromegrass appeared to be slightly higher with the highest rate of aluminum and iron sludges (Table 79). Lead concentration in corn grain and stover was not affected by treatment.

Zinc concentrations in bromegrass and in corn stover in both trials increased with increasing rates of application of all three sludges (Table 80, 81 and 82). In the bromegrass and in the corn stover from Cambridge, zinc concentration was also increased, but to a lesser extent, by ammonium nitrate. The calcium sludge increased zinc concentration least, and the aluminum sludge the most in the corn stover but the iron and aluminum sludges produced similar results in the bromegrass. There may have been some increase in the zinc concentration in corn grain from Elora and Cambridge where high rates of sludge were applied (Table 64).

Zinc concentration in bromegrass and corn stover from selected treatments are presented for the period 1973 to 1977 in Tables 83 and 84. There does not appear to be an increase in zinc concentration in the bromegrass from year to year. There appears to be an increase in zinc concentration in the Elora corn stover from year to year with all three sludges applied at the 1600 kg N/ha rate. The corn stover data from Cambridge are quite variable so that it is difficult to determine if there is a pattern.

Molybdenum concentration in bromegrass appeared to have been increased by all three sludges when applied at the highest rate (Table 85). In cor grain and stover from both Elora and Cambridge, the molybdenum concentration appears to have been increased by the calcium sludge (Table 86). This may be due to the higher soil pH resulting from the calcium sludge.

Antimony concentrations in bromegrass and corn grain and stover were unaffected by treatment (Tables 85 and 86). The concentrations in the corn grain were low.

Cobalt concentrations in both bromegrass and corn were unaffected by treatment (Tables 85 and 86).

Mercury concentrations in bromegrass and corn stover and grain were not affected by treatment (Table 85 and 86).

Selenium concentrations in bromegrass and in corn grain and stover appeared to be unaffected by treatment (Tables 85 and 86).

4.3.2 Nitrilotriacetic acid (NTA)-extractable soil Cd, Cu, Ni and Zn from surface soil (0-15 cm)

In November 1977, after harvest of the corn, the surface soils (0-15 cm) of the three experiments were sampled for metal analysis, using NTA as an extractant. The results are presented in Table 87.

Cadmium extracted by NTA was increased by both the aluminum and iron sludges. This pattern was also observed in concentrations in bromegrass and corn stover (Tables 61, 62 and 63). The aluminum sludge supplied the most cadmium through the years (Tables 12, 13 and 14). The use of the high cadmium sludge from Guelph in 1976 and 1977 rapidly increased the soil cadmium in the past two years. The calcium sludge did not increase the NTA-extractable cadmium, probably because of the higher soil pH, and the lower amounts of cadmium supplied in the sludge.

Copper extracted by NTA was increased by all sludges but particularly the aluminum and iron sludges, which supplied the most copper to the soil.

Nickel extracted by NTA was greatly increased by the calcium sludge, and to a lesser extent by the highest rate of the aluminum sludge in all three trials. This pattern is similar to that shown in the concentrations in plants both with bromegrass and corn stover. The high

NTA-extractable nickel in the calcium sludge plots was caused by the high nickel sludge from Midland.

Zinc extracted by NTA was higher in the sludge treatments, with the aluminum sludge having the greatest effect, and the calcium sludge having similar or less effect than the iron sludge. The amount of Zn supplied in sludge through the years 1973 to 1977 was in the order aluminum sludge > calcium sludge > iron sludge. The higher pH associated with the calcium sludge plots probably reduced the availability of zinc somewhat, while the lower soil pH associated with the use of the iron sludge may have increased its Zn availability in the soil. The calcium sludge also resulted in lower uptake of Zn by plants than the other sludges as shown by the concentrations in bromegrass and corn stover (Tables 80, 81 and 82).

4.3.3 Summary and conclusions

Sewage sludge produced as high and frequently higher yields of bromegrass and corn than did ammonium nitrate. From total nitrogen and nitrate concentrations in the crops there is some indication that nitrogen in the calcium sludge was less available to the crops than that in the other two sludges. In 1977 less of the nitrogen in the calcium sludge was in the ammonium form when it was added (Tables 11, 13 and 15).

Phosphorus added in the calcium sludge was much more effective than phosphorus in the other sludges in raising the sodium bicarbonate soluble soil phosphorus level. The crops did not appear to be very sensitive to differences in soil phosphorus concentrations, probably because concentrations in the soils and crops were well above levels where response is expected.

Iron and aluminum concentrations in the crops were not affected by treatment.

As expected soil pH and soil calcium increased with additions of the calcium sludge. The iron sludge appeared to lower pH more than did the aluminum sludge. It is probable that this difference was due to the lower content of calcium and magnesium in the iron sludge.

Cadmium, copper, nickel, zinc and molybdenum concentrations in bromegrass and corn stover were increased by high rates of sewage sludge application. Cadmium, copper and zinc concentrations in bromegrass and corn stover appeared to be increased by application of ammonium nitrate but to a lesser extent than with sewage sludge. The effect of ammonium nitrate on availability of metals is believed to be due to increased solubility of calcium and magnesium carbonates in these soils and to decreased soil pH. With copper, nickel and zinc there is some limited evidence for increased concentrations in the corn grain with high rates of sludge application.

Cadmium concentration in corn stover appeared to increase from year to year and zinc followed a similar pattern in the corn stover from Elora. Nickel concentration in bromegrass and corn stover increased from year to year with repeated applications of calcium sludge but this was probably due largely to the very high nickel sludge used in the last two years.

Chromium concentration was increased slightly in corn stover from Cambridge when aluminum sludge was applied.

Antimony, boron, cobalt, mercury and selenium concentrations in the crops were not affected by treatment.

Amounts of metals extracted from the surface soils with NTA reflected in a general way the amounts of metals added in the sludges and the concentrations in the crops.

TABLE 10. CHEMICAL COMPOSITION OF SLUDGES OBTAINED FROM TREATMENT PLANTS ON VARIOUS DATES (fluid weight basis).

Sludge and Source	Load* No.	Date	pH	D.M.	Total N	Sol. & Exch. NH_4-N	P	K	Ca	Mg	Na	Al	Fe
				mg/ml									
Calcium Midland	1	18/4/77	6.5	70.3	1.0	0.14	3.2	0.1	3.4	0.3	0.1	1.1	6.2
	2	25/4/77	6.6	66.4	1.0	0.15	3.2	0.1	3.3	0.3	0.1	1.0	6.0
	7	17/5/77	6.6	65.3	1.1	0.16	3.4	0.1	3.0	0.3	0.1	1.0	7.8
	10	9/6/77	7.6	43.0	0.8	0.18	2.2	0.1	1.0	0.2	0.1	0.7	4.6
	13	18/7/77	7.0	81.0	1.4	0.19	3.8	0.2	4.9	0.3	0.1	1.1	7.7
Aluminum Guelph	4	22/4/77	6.9	35.4	1.6	0.46	1.3	0.1	2.1	0.2	0.1	1.1	1.4
	5	2/5/77	6.9	38.3	1.7	0.44	1.4	0.1	2.6	0.3	0.1	1.1	1.5
	9	18/5/77	6.9	42.5	1.8	0.45	1.5	0.1	3.7	0.3	0.2	1.1	1.5
	11	9/6/77	7.4	30.0	1.2	0.38	1.1	0.1	2.6	0.3	0.2	0.5	1.2
	15	20/7/77	7.3	58.0	2.6	0.87	2.3	0.1	4.8	0.3	0.2	1.6	2.2
Iron North Toronto	3	26/4/77	7.0	64.0	3.0	0.89	3.3	0.2	2.7	0.4	0.2	0.9	4.7
	6	12/5/77	6.9	67.4	3.1	0.95	3.3	0.2	2.8	0.4	0.2	0.9	4.6
	8	17/5/77	7.0	65.1	3.1	0.94	3.2	0.2	2.5	0.4	0.2	1.0	4.7
	12	10/6/77	7.2	68.0	3.0	1.03	3.2	0.3	1.0	0.3	0.2	0.9	5.3
	14	18/7/77	7.3	71.0	2.7	0.63	3.3	0.2	1.2	0.3	0.2	1.1	5.4

* Load No. 1, 3 and 4 were used for the 1st 1977 application to the bromegrass trial. Load No. 10, 11 and 12, and Load No. 13, 14 and 15, respectively were used in the second and third applications to the bromegrass trial.

Load No. 2, 5 and 6 were used on the Elora corn trial and Load No. 7, 8 and 9 were used on the Cambridge corn trial.

TABLE 10. (CONT'D)

Sludge	Date	B	Cd	Cr	Co	Cu	Hg	Mn	Mo	Ni	Pb	Zn	Sb	Se
		μg/ml											-ng/ml-	
Calcium Midland	18/4/77	2.0	0.67	154	5.0	70	0.57	55	2.1	410	44	229	42	14
	25/4/77	2.0	0.55	144	2.8	53	0.56	55	1.7	304	43	232	35	7
	17/5/77	2.5	0.54	155	1.4	46	0.56	57	1.4	242	51	261	56	10
	9/6/77	2.2	0.37	114	0.65	27	0.38	26	0.95	172	29	183	42	4
	18/7/77	2.7	0.65	247	1.4	46	0.99	37	0.74	214	46	296	32	12
Aluminum Guelph	22/4/77	1.4	2.60	95	0.30	65	0.25	10	1.3	2.8	55	549	6	<1
	2/5/77	1.5	2.80	105	0.33	77	0.29	10	1.4	4.1	60	575	7	<1
	18/5/77	1.7	3.42	111	0.36	87	0.30	12	1.5	4.6	73	552	9	<1
	9/6/77	1.7	2.63	74	0.26	53	0.18	5.4	1.0	2.6	44	405	3	<1
	20/7/77	2.3	6.67	175	0.80	161	0.46	11	1.7	5.1	116	798	13	5
Iron North Toronto	26/4/77	1.0	1.40	47	0.63	122	1.43	69	2.3	1.5	120	141	20	6
	12/5/77	1.5	1.40	47	0.86	118	1.55	71	2.5	1.7	121	144	36	4
	17/5/77	1.2	1.40	48	0.74	114	1.63	72	2.5	1.6	122	148	21	3
	10/6/77	1.2	1.50	48	0.61	107	1.84	51	2.7	1.2	105	143	35	8
	18/7/77	0.9	1.49	39	1.06	108	1.63	39	1.8	2.1	107	151	27	4

TABLE 11. AMOUNTS OF VARIOUS CONSTITUENTS IN SLUDGES ADDED TO BROMEGRASS EXPERIMENT IN FIRST APPLICATION AND THE TOTAL OF THREE APPLICATIONS AT 200 kg N/ha/ANNUM IN 1977

Constituent	Ca-sludge		Al-sludge		Fe-sludge	
	1st Application	Total	1st Application	Total	1st Application	Total
	kg/ha					
Dry solids	4,687	12,100	1,475	4,630	1,422	4,690
Total N	66.7	200	66.7	200	66.7	200
Soluble & Exch. NH_4-N	9.3	33	19	62	20	59
P	213	577	54	174	73	225
K	6.7	24.5	4.2	12.4	4.4	16.0
Ca	227	543	88	355	60	112
Mg	20	51	8.3	33	8.9	23
Na	6.7	20	4.2	20	4.4	14
Al	71	178	44	115	21	69
Fe	410	1164	58	177	104	355
Mn	3.7	7.7	0.4	1.0	1.5	3.6
Cd	0.05	0.11	0.11	0.43	0.3	0.10
Cr	10	32	4.0	13	1.0	3.1
Cu	4.7	9.2	2.7	9.7	2.7	7.8
Mo	0.14	0.25	0.05	0.15	0.05	0.16
Ni	27	52	0.12	0.39	0.03	0.11
Pb	2.9	7.5	2.3	7.7	2.7	7.6
Zn	15.3	45	22.9	66	3.1	10
Hg	0.038	0.12	0.010	0.03	0.031	0.11
Se	<0.001	<0.002	<0.001	<0.001	<0.001	<0.001
B	0.13	0.44	0.06	0.21	0.02	0.07
Co	0.33	0.45	0.013	0.048	0.014	0.054
Sb	0.003	0.008	<0.001	<0.001	<0.001	0.002

TABLE 12. TOTAL AMOUNTS OF VARIOUS CONSTITUENTS ADDED TO THE BROMEGRASS EXPERIMENT BY ANNUAL APPLICATION OF VARIOUS SLUDGES AT 178 lb N/ac (200 kg N/ha) FROM 1973 TO 1977

	Ca-sludge		Al-sludge		Fe-sludge	
			lb/ac	(kg/ha)		
Dry solids	52,500	(58,900)	20,800	(23,300)	19,200	(21,500)
Total N	892	(1,000)	892	(1,000)	892	(1,000)
Soluble & exch. NH_4-N	201	(225)	299	(335)	282	(316)
P_2O_5	2,540		1,660		1,990	
P		(1,240)		(810)		(970)
K_2O	96		77		90	
K		(90)		(72)		(84)
Ca	8,940	(10,020)	1,262	(1,415)	715	(802)
Mg	334	(374)	140	(157)	122	(137)
Na	116	(130)	106	(119)	54	(60)
Al	336	(377)	870	(975)	269	(302)
Fe	1,390	(1,560)	359	(402)	1,115	(1,250)
Mn	22	(25)	4.0	(4.5)	9.5	(10.7)
Cd	0.28	(0.31)	0.80	(0.90)	0.40	(0.45)
Cr	37	(41)	77	(86)	9.5	(10.6)
Cu	19	(21)	25	(28)	27	(31)
Ni	70	(78)	3.7	(4.2)	0.62	(0.69)
Pb	14.0	(15.7)	17.0	(19.1)	33	(37)
Zn	84	(94)	118	(132)	55	(62)
B	1.3	(1.5)	0.65	(0.73)	0.42	(0.47)
Hg	0.27	(0.30)	0.09	(0.10)	0.40	(0.45)
Mo	0.45	(0.51)	0.31	(0.35)	0.39	(0.44)
Se	0.029	(0.032)	0.061	(0.068)	0.001	(0.001)

TABLE 13. TOTAL AMOUNTS OF VARIOUS CONSTITUENTS ADDED IN SLUDGES IN 1977 AT 178 lb N/ac (200 kg N/ha) TO CORN EXPERIMENT AT ELORA.

	Ca-sludge		Al-sludge		Fe-sludge	
			lb/ac	(kg/ha)		
Solids	11,850	(13,280)	4,020	(4,510)	3,880	(4,350)
Total N	178	(200)	178	(200)	178	(200)
Soluble + Exch NH_4-N	27	(30)	46	(52)	54	(61)
P_2O_5	1,310		337		436	
P		(640)		(165)		(213)
K_2O	22		13		14	
K		(20)		(12)		(13)
Ca	589	(660)	276	(309)	161	(181)
Mg	54	(60)	31	(35)	23	(26)
Na	18	(20)	11	(12)	12	(13)
Al	178	(200)	114	(128)	54	(60)
Fe	1,070	(1,200)	171	(192)	263	(295)
Mn	10	(11)	1.1	(1.2)	4.1	(4.6)
Cd	0.10	(0.11)	0.29	(0.33)	0.08	(0.09)
Cr	26	(29)	11	(12)	2.7	(3.0)
Cu	9.5	(10.6)	8.1	(9.1)	6.8	(7.6)
Ni	54	(61)	0.43	(0.48)	0.10	(0.11)
Pb	7.7	(8.6)	6.3	(7.1)	7.0	(7.8)
Zn	41	(46.4)	60.3	(67.6)	8.3	(9.3)
B	0.37	(0.40)	0.16	(0.18)	0.09	(0.10)
Hg	0.10	(0.11)	0.03	(0.03)	0.09	(0.10)
Se	0.001	(0.001)	<0.001	(<0.001)	<0.001	(<0.001)
Mo	0.30	(0.34)	0.14	(0.16)	0.14	(0.16)
Co	0.50	(0.56)	0.04	(0.04)	0.05	(0.06)
Sb	0.09	(0.10)	<0.001	(<0.001)	0.001	(0.001)

TABLE 14. TOTAL AMOUNTS OF VARIOUS CONSTITUENTS ADDED TO ELORA CORN EXPERIMENT BY ANNUAL APPLICATION OF VARIOUS SLUDGES AT 178 lb N/ac (200 kg N/ha) FROM 1973 TO 1977.

	Ca-sludge		Al-sludge		Fe-sludge	
			lb/ac	(kg/ha)		
Dry solids	44,500	(49,900)	19,900	(22,300)	18,800	(21,050)
Total N	892	(1,000)	892	(1,000)	892	(1,000)
Soluble & exch. NH_4-N	264	(296)	311	(349)	284	(318)
P_2O_5	2,190		1,640		1,950	
P		(1,065)		(790)		(953)
K_2O	116		70		88	
K		(108)		(66)		(82)
Ca	7,090	(7,950)	1,080	(1,210)	760	(850)
Mg	239	(268)	139	(156)	120	(135)
Na	84	(94)	74	(83)	57	(64)
Al	304	(341)	681	(763)	198	(222)
Fe	1,445	(1,620)	336	(377)	1,227	(1,375)
Mn	24	(27)	4.3	(4.8)	10.5	(11.8)
Cd	0.21	(0.24)	0.67	(0.75)	0.42	(0.47)
Cr	27	(30)	69	(77)	8.8	(9.9)
Cu	16.5	(18.5)	24	(27)	27	(31)
Ni	55	(62)	3.3	(3.7)	0.55	(0.62)
Pb	13.8	(15.5)	15.3	(17.2)	35	(39)
Zn	77	(86)	111	(125)	55	(61)
B	0.70	(0.78)	0.35	(0.39)	0.41	(0.46)
Hg	0.17	(0.19)	0.09	(0.10)	0.39	(0.44)
Mo	0.53	(0.59)	0.45	(0.50)	0.61	(0.68)
Se	0.022	(0.025)	0.032	(0.036)	0.001	(0.001)

TABLE 15. TOTAL AMOUNTS OF VARIOUS CONSTITUENTS ADDED IN SLUDGE IN 1977 AT 178 lb N/ac (200 kg N/ha) TO CORN EXPERIMENT AT CAMBRIDGE

	Ca-sludge		Al-sludge		Fe-sludge	
			lb/ac	(kg/ha)		
Solids	10,590	(11,870)	4,210	(4,720)	3,750	(4,200)
Total N	178	(200)	178	(200)	178	(200)
Soluble + Exch NH_4-N	26	(29)	46	(50)	54	(61)
P_2O_5	1,264		342		421	
P		(618)		(167)		(206)
K_2O	19		12		14	
K		(18)		(11)		(13)
Ca	486	(545)	367	(411)	144	(161)
Mg	50	(56)	29	(33)	23	(26)
Na	16	(18)	20	(22)	12	(13)
Al	159	(178)	104	(117)	55	(62)
Fe	1,271	(1,425)	144	(161)	272	(305)
Mn	8.9	(10)	1.2	(1.3)	4.1	(4.6)
Cd	0.09	(0.10)	0.34	(0.38)	0.08	(0.09)
Cr	25	(28)	11.0	(12.3)	2.8	(3.1)
Cu	7.5	(8.4)	8.6	(9.7)	6.6	(7.4)
Ni	39	(44)	0.45	(0.51)	0.09	(0.10)
Pb	8.3	(9.3)	7.2	(8.1)	7.0	(7.9)
Zn	42	(47.5)	55	(61.3)	8.5	(9.5)
B	0.40	(0.45)	0.17	(0.19)	0.07	(0.08)
Hg	0.09	(0.10)	0.03	(0.03)	0.10	(0.11)
Se	0.002	(0.002)	<0.001	(<0.001)	<0.001	(<0.001)
Mo	0.22	(0.25)	0.15	(0.17)	0.14	(0.16)
Co	0.22	(0.25)	0.04	(0.04)	0.04	(0.05)
Sb	0.01	(0.01)	<0.001	(<0.001)	0.001	(0.001)

TABLE 16. TOTAL AMOUNTS OF VARIOUS CONSTITUENTS ADDED TO THE CAMBRIDGE CORN EXPERIMENT BY ANNUAL APPLICATION OF VARIOUS SLUDGES AT 178 lb N/ac (200 kg N/ha) FROM 1973 TO 1977.

	Ca-sludge		Al-sludge		Fe-sludge	
			lb/ac	(kg/ha)		
Dry solids	55,600	(62,400)	21,600	(24,200)	18,600	(20,900)
Total N	892	(1,000)	892	(1,000)	892	(1,000)
Soluble & exch. NH_4-N	203	(228)	304	(341)	304	(341)
P_2O_5	2,380		1,650		1,980	
P		(1,180)		(805)		(968)
K_2O	98		58		80	
K		(92)		(55)		(75)
Ca	9,760	(10,900)	1,312	(1,470)	710	(800)
Mg	271	(304)	150	(168)	125	(140)
Na	89	(100)	81	(91)	62	(69)
Al	346	(388)	1,504	(1,687)	219	(246)
Fe	1,570	(1,760)	400	(450)	1,220	(1,370)
Mn	25	(28)	4.5	(5.0)	10.7	(12.0)
Cd	0.30	(0.33)	0.82	(0.93)	0.38	(0.43)
Cr	38	(42)	82	(92)	16	(18)
Cu	20	(22)	27	(30)	27	(30)
Ni	60	(67)	4.0	(4.5)	1.0	(1.1)
Pb	17	(19)	19	(21)	33	(36)
Zn	87	(98)	115	(129)	58	(65)
B	1.0	(1.1)	0.55	(0.62)	0.30	(0.33)
Hg	0.22	(0.25)	0.10	(0.11)	0.36	(0.40)
Mo	0.51	(0.57)	0.47	(0.53)	0.83	(0.93)
Se	0.016	(0.018)	0.030	(0.034)	0.001	(0.001)

TABLE 17. DATES OF SLUDGE AND NITROGEN FERTILIZER APPLICATIONS AND FORAGE HARVEST, BROMEGRASS EXPERIMENT, 1977.

Operation	1st	2nd	3rd
NH_4NO_3 addition	April 25	June 10	July 21
Ca-sludge addition	April 26	June 10	July 21
Al-sludge addition	April 25	June 10	July 21
Fe-sludge addition	April 29	June 10	July 21
Harvest	June 8	July 20	Sept. 6

TABLE 18. FIELD OPERATIONS ON RATE AND SOURCE OF SLUDGE EXPERIMENT WITH CORN, 1977.

Treatment or Description	Elora	Cambridge
Soil	Conestoga loam	Caledon loamy sand
Plowed	April 20	April 13
Calcium sludge applied	May 2	May 19
Iron sludge applied	May 12	May 17
Alum sludge applied	May 3	May 18
Phosphate applied to ammonium nitrate plots and disked in before seeding	104 lb P_2O_5/ac (50 kg P/ha)	No phosphate required
Potassium applied to all treatments and disked in before seeding	97 lb K_2O/ac (90 kg K/ha)	43 lb K_2O/ac (40 kg K/ha)
Seeding	May 18	May 27
(60 lb of 6-18-6 liquid fertilizer per acre banded with seed on all treatments)		
Emerged plants counted	May 30	June 7
Thinning and sampling* of seedlings	June 14	June 21
Silk and final stand counts	July 27	August 3
Final stand (plants/ac)	23,000	16,000
Plant height to flag leaf measurement	August 26	August 26
Count of lodged plants	October 11	October 17
Grain harvested	October 11	October 17
Stover harvested	October 20	October 25

* Five to seven leaf stage

TABLE 19. DRY MATTER YIELD OF FIRST CUT (June 8), BROMEGRASS. ELORA, 1977.

Nitrogen Rate		Nitrogen Source				Sludge Average
lb/ac	(kg/ha)	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	
		lb/ac (kg/ha)				
0	(0)	1990 (2230)g*				
89	(100)	3250 (3640)f				
178	(200)	4060 (4550)b-e	3680 (4130)d-f	3550 (3980)ef	4360 (4880)a-d	3860 (4330)
356	(400)	4590 (5140)abc	4940 (5530)a	4940 (5540)a	4660 (5220)abc	4840 (5430)
712	(800)		4850 (5440)a	4520 (5060)abc	4700 (5270)ab	4690 (5260)
1424	(1600)		3950 (4420)cd	4770 (5340)ab	4460 (5000)a-e	4390 (4920)
Average			4350 (4880)	4440 (4980)	4540 (5090)	4447 (4980)

C.V. = 8.9%

Individual treatments not followed by a common letter are significantly different at 0.05 probability by Duncan's Multiple Range Test.

Rates of sludge and NH_4NO_3 are significantly different at 0.01 probability and the source-rate interaction at 0.05 probability by "F" test

TABLE 20. DRY MATTER YIELD OF SECOND CUT (July 20), BROMEGRASS. ELORA, 1977.

Nitrogen Rate lb/ac	(kg/ha)	Nitrogen Source								Sludge Average	
		Ammonium Nitrate		Calcium Sludge		Aluminum Sludge		Iron Sludge			
		lb/ac (kg/ha)									
0	(0)	369	(414)h*								
89	(100)	1480	(1660)f								
178	(200)	2220	(2480)de	1113	(1250)g	1380	(1550)fg	1110	(1250)g	1200	(1350)
356	(400)	2320	(2610)d	1990	(2240)e	2220	(2490)de	2110	(2370)de	2110	(2360)
712	(800)			2770	(3110)bc	2780	(3110)bc	2630	(2950)c	2730	(3060)
1424	(1600)			3100	(3480)a	3090	(3470)a	3010	(3370)ab	3070	(3440)
Average				2240	(2520)	2370	(2660)	2220	(2480)	2280	(2552)

C.V. = 7.5%

Individual treatments not followed by a common letter are significantly different at 0.05 probability by Duncan's Multiple Range Test.

Rates of sludge and NH_4NO_3 are significantly different at 0.01 probability by "F" test.

TABLE 21. DRY MATTER YIELD OF THIRD CUT (September 6), BROMEGRASS. ELORA, 1977.

Nitrogen Rate lb/ac (kg/ha)	Nitrogen Source				Sludge Average
	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	
	lb/ac (kg/ha)				
0 (0)	359 (403)c*				
89 (100)	1010 (1140)bc				
178 (200)	980 (1100)c	1340 (1500)a	1330 (1490)a	1330 (1500)a	1330 (1500)
356 (400)	950 (1070)c	1320 (1480)a	1190 (1340)abc	1310 (1470)ab	1270 (1430)
712 (800)		1140 (1270)abc	1060 (1180)abc	1160 (1300)abc	1120 (1250)
1424 (1600)		950 (1060)c	627 (703)d	1180 (1320)abc	920 (1030)
Average		1190 (1330)	1050 (1180)	1240 (1400)	1160 (1300)

C.V. = 14.9%

Individual treatments not followed by a common letter are significantly different at 0.05 probability by Duncan's Multiple Range Test.

Rates of sludge and of NH_4NO_3 are significantly different at 0.01 probability and source of sludge is significant 0.05 probability by "F" test.

TABLE 22. TOTAL DRY MATTER YIELD OF BROMEGRASS (3 cuts). ELORA, 1977.

Nitrogen Rate lb/ac (kg/ha)	Nitrogen Source				Sludge
	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Average
	lb/ac (kg/ha)				
0 (0)	2720 (3050)g*				
89 (100)	5740 (6440)f				
178 (200)	7250 (8130)cd	6140 (6880)ef	6260 (7020)ef	6810 (7630)de	6400 (7180)
356 (400)	7870 (8820)bc	8250 (9250)ab	8350 (9370)ab	8080 (9050)ab	8230 (9220)
712 (800)		8760 (9820)a	8350 (9360)ab	8490 (9510)ab	8530 (9560)
1424 (1600)		7990 (8960)abc	8490 (9510)ab	8650 (9690)ab	8370 (9390)
Average		7790 (8730)	7860 (8820)	8000 (8970)	7880 (8840)

C.V. = 6.1%

Individual treatments not followed by a common letter are significantly different at 0.05 probability by Duncan's Multiple Range Test.

Rates of sludge and NH_4NO_3 are significantly different at 0.01 probability by "F" test.

TABLE 23. TOTAL DRY MATTER YIELD OF BROMEGRASS (3 cuts). ELORA, 1976.

Nitrogen Rate lb/ac (kg/ha)	Nitrogen Source				Sludge Average
	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	
	lb/ac (kg/ha)				
0 (0)	2740 (3070) a				
89 (100)	5620 (6300) bc				
178 (200)	6020 (6750) bcd	6300 (7070) bcde	5350 (6000) b	6250 (7000) bcde	5970 (6690)
356 (400)	6370 (7140) cdef	7320 (8200) f	7010 (7860) def	6270 (7030) bcde	6870 (7700)
712 (800)		6800 (7620) def	6440 (7210) cdef	6600 (7400) cde	6610 (7410)
1424 (1600)		6450 (7230) cdef	7120 (7980) ef	7200 (8070) ef	6920 (7760)
Average		6720 (7530)	6480 (7260)	6580 (7370)	6590 (7390)

C.V. = 8.4%

Individual treatments not followed by a common letter are significantly different at 0.05 probability by Duncan's Multiple Range Test.

Rates of sludge are significantly different at 0.01 probability and the source-rate interaction at 0.05 probability by "F" test.

TABLE 24. TOTAL DRY MATTER YIELD OF BROMEGRASS (3 cuts). ELORA, 1975.

Nitrogen Rate lb/ac (kg/ha)	Nitrogen Source				Sludge Average
	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	
	lb/ac (kg/ha)				
0 (0)	1497 (1679) h*				
89 (100)	4465 (5005) fg				
178 (200)	5591 (6268) de	3764 (4220) g	4974 (5576) ef	5007 (5614) ef	4582 (5136)
356 (400)	6065 (6799) cd	5620 (6301) de	6675 (7483) bc	6441 (7220) bc	6245 (7001)
712 (800)		7088 (7947) ab	7148 (8013) ab	6972 (7816) ab	7069 (7925)
1424 (1600)		7544 (8458) a	6853 (7683) ab	7232 (8108) ab	7210 (8083)
Average	4405 (4938)	6004 (6731)	6412 (7189)	6413 (7189)	6276 (7036)

C.V. = 7.8%

*individual treatments not followed by a common letter are significantly different at 0.05 probability.

Level of significance of various effects by "F" test.

Sources of sludge	N.S.
Rates of sludge	0.01
Sludge x rate interaction	0.05
Rates of ammonium nitrate	0.01

TABLE 25. TOTAL DRY MATTER YIELD OF BROMEGRASS (3 cuts). ELORA, 1974.

Nitrogen Rate lb/ac (kg/ha)	Nitrogen Source Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average
	dry matter - lb/ac (kg/ha)				
0 (0)	890 (990)^{2*}				
89 (100)	2750 (3080)^{bc}				
178 (200)	4120 (4620)^{cf}	2160 (2420)^{b}	3220 (3600)^{cd}	3060 (3430)^{cd}	2810 (3150)
356 (400)	6030 (6750)^{h}	3650 (4090)^{de}	4820 (5410)^{g}	4770 (5340)^{fg}	4410 (4950)
712 (800)		6340 (7100)^{h}	6060 (6790)^{h}	6240 (6990)^{h}	6210 (6960)
1424 (1600)		6990 (7840)	6150 (6896)^{h}	5960 (6680)^{h}	6370 (7140)
Average**		4790 (5360)	5060 (5680)	5010 (5610)	4950 (5550)

* Individual treatment means not followed by a common letter are significantly different at 0.05 probability

Rates of sludge and of ammonium nitrate are significantly different at 0.01 probability by "F" test.

Source x rate interaction is significant at 0.01 probability level.

TABLE 26. EFFECT OF RATE AND SOURCE OF NITROGEN ON CORN STOVER YIELD FROM ELORA, 1977.

Nitrogen Rate lb/ac (kg/ha)		Nitrogen Source				Sludge Average
		Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	
		lb/ac (kg/ha)				
0	(0)	4030 (4510)				
89	(100)	3700 (4140)				
178	(200)	4110 (4600)	4200 (4700)	3830 (4300)	4100 (4600)	4040 (4530)
356	(400)	3770 (4230)	3700 (4140)	3890 (4370)	3760 (4220)	3790 (4240)
712	(800)		3720 (4160)	3720 (4170)	4110 (4610)	3850 (4310)
1424	(1600)		3770 (4220)	3700 (4150)	4240 (4750)	3900 (4370)
Average			3840 (4310)	3790 (4250)	4060 (4550)	3900 (4370)

C.V. = 11%

There were no significant differences between treatment effects by 'F' test or DMR test at 0.05 probability.

TABLE 27. EFFECT OF RATE AND SOURCE OF NITROGEN ON CORN STOVER YIELD FROM CAMBRIDGE, 1977.

Nitrogen Rate	Nitrogen Source				Sludge
lb/ac (kg/ha)	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Average
	lb/ac (kg/ha)				
0 (0)	3340 (3740)bc*				
89 (100)	3550 (3970)abc				
178 (200)	3640 (4080)abc	3660 (4100)abc	4000 (4480)ab	3740 (4190)abc	3800 (4260)
356 (400)	3090 (3460)c	3680 (4120)abc	3470 (3880)abc	3900 (4350)abc	3680 (4120)
712 (800)		3230 (3620)bc	3520 (3940)abc	4300 (4820)a	3680 (4130)
1424 (1600)		3710 (4150)abc	3950 (4420)abc	4240 (4750)a	3960 (4440)
Average		3570 (4000)	3730 (4180)	4050 (4530)	3780 (4240)

C.V. = 12%

* Individual treatments followed by a common letter are not significantly different at 0.05 probability by Duncan's Multiple Range Test.

Sources of sludge and rates of NH_4NO_3 are significantly different by 'F' test at 0.05 probability.

TABLE 28. EFFECT OF RATE AND SOURCE OF NITROGEN ON CORN GRAIN YIELD FROM ELORA, 1977.

Nitrogen Rate lb/ac (kg/ha)		Nitrogen Source				Sludge Average
		Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	
		lb/ac (kg/ha)				
0	(0)	5870 (6580)c*				
89	(100)	6910 (7740)ab				
178	(200)	7010 (7860)ab	6900 (7740)ab	6860 (7690)ab	7370 (8270)a	7050 (7900)
356	(400)	6680 (7480)b	6890 (7720)ab	6960 (7800)ab	7010 (7850)ab	6950 (7890)
712	(800)		7300 (8180)ab	6960 (7800)ab	7470 (8370)a	7240 (8120)
1424	(1600)		7210 (8080)ab	7340 (8230)ab	7250 (8130)ab	7270 (8150)
Average			7070 (7930)	7030 (7880)	7280 (8160)	7130 (7990)

C. V. = 5%

* Individual treatments followed by a common letter are not significantly different at 0.05 probability by Duncan's Multiple Range Test.

Rates of NH_4NO_3 are significantly different at 0.01 probability by 'F' test.

TABLE 29. EFFECT OF RATE AND SOURCE OF NITROGEN ON CORN GRAIN YIELD FROM CAMBRIDGE, 1977.

Nitrogen Rate lb/ac (kg/ha)	Nitrogen Source				Sludge Average
	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	
	lb/ac (kg/ha)				
0 (0)	4700 (5260)e*				
89 (100)	5000 (5590)cde				
178 (200)	4860 (5450)de	5570 (6230)a-d	5670 (6350)abc	5690 (6380)abc	5640 (6320)
356 (400)	4660 (5220)e	5640 (6320)abc	5810 (6500)ab	5890 (6590)ab	5780 (6470)
712 (800)		5640 (6320)abc	5440 (6090)bcd	5940 (6650)ab	5670 (6350)
1424 (1600)		5700 (6390)abc	5980 (6700)ab	6300 (7050)a	5990 (6710)
Average		5640 (6310)	5730 (6410)	5950 (6670)	5770 (6470)

C.V. = 7.5%

* Individual treatments followed by a common letter are not significantly different at 0.05 probability by Duncan's Multiple Range Test.

Rates of NH_4NO_3 Were significantly at 0.01 probability by 'F' test.

TABLE 30. NITROGEN CONCENTRATION IN FIRST CUT (June 8), BROMEGRASS. ELORA, 1977.

Nitrogen Rate lb/ac (kg/ha)	Nitrogen Source				Sludge Average
	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	
		%N			
0 (0)	1.88f*				
89 (100)	2.03ef				
178 (200)	2.60d	1.90f	1.88f	1.98ef	1.92
356 (400)	3.30a	2.20e	2.52d	2.72cd	2.48
712 (800)		2.77cd	2.95bc	2.97bc	2.89
1424 (1600)		3.17ab	3.20ab	3.08ab	3.15
Average		2.51	2.64	2.69	2.61

C.V. =6.3%

* Individual treatments not followed by a common letter are significantly different at 0.05 probability level by Duncan's Multiple Range Test.

Rates of ammonium nitrate and sludge are significantly different at 0.01 probability level by 'F' test. Source of sludge is significant at 0.05 probability level

TABLE 31. NITROGEN CONCENTRATION IN CORN STOVER. ELORA, 1977.

Nitrogen Rate lb/ac	(kg/ha)	Nitrogen Source				Sludge Average
		Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	
			% N			
0	(0)	0.85b*				
89	(100)	1.10a				
178	(200)	1.10a	1.12a	1.03ab	1.03ab	1.06
356	(400)	1.05a	1.07a	1.02ab	1.15a	1.08
712	(800)		1.08a	1.15a	1.00ab	1.08
1424	(1600)		1.17a	1.12a	1.18a	1.16
Average			1.11	1.08	1.09	1.09

C.V. = 10%

* Individual treatments not followed by a common letter are significantly different at the 0.05 probability level by Duncan's Multiple Range Test.

Rates of NH_4NO_3 are significantly different at 0.05 probability by 'F' test.

TABLE 32. NITROGEN CONCENTRATION IN CORN STOVER. CAMBRIDGE, 1977.

Nitrogen Rate lb/ac	(kg/ha)	Nitrogen Source Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average
			% N			
0	(0)	0.77b*				
89	(100)	1.10a				
178	(200)	1.25a	1.08a	1.07a	1.17a	1.11
356	(400)	1.27a	1.18a	1.17a	1.10a	1.15
712	(800)		1.07a	1.13a	1.18a	1.13
1424	(1600)		1.22a	1.20a	1.25a	1.22
Average			1.14	1.14	1.18	1.15

C.V. = 12%

* Individual treatments not followed by a common letter are significantly different at the 0.05 probability level by Duncan's Multiple Range Test.

Rates of NH_4NO_3 are significantly different at 0.01 probability by 'F' test

TABLE 33. NUTRIENT CONTENT OF CORN GRAIN, ELORA AND CAMBRIDGE, 1977.

Element	Source of Nitrogen					C.V.%
	Ammonium Nitrate		Calcium Sludge	Alum Sludge	Iron Sludge	
	N rate - lb/ac (kg/ha)					
	89 (100)	356 (400)	1424 (1600)	1424 (1600)	1424 (1600)	
			Elora			
N %	1.85*	1.78	1.78	1.85	1.87	3.7
P %	0.34	0.28	0.26	0.28	0.29	19
K %	0.46	0.39	0.39	0.41	0.40	15
Mg %	0.13	0.11	0.11	0.11	0.11	20
			Cambridge			
N %	2.00b	2.08a	1.97b	1.95b	2.08a	2.0
P %	0.29	0.33	0.28	0.27	0.33	17
K %	0.38	0.45	0.40	0.39	0.45	12
Mg %	0.11	0.13	0.11	0.10	0.13	19

* Values followed by a common letter are not significantly different at 0.05 probability level by Duncan's Multiple Range test. Individual rows of values without any letter indicate that treatment differences are not significantly different.

TABLE 34. NITRATE-N CONCENTRATION IN FIRST CUT (June 8), BROMEGRASS. ELORA, 1977.

Nitrogen Rate	Nitrogen Source				Sludge
lb/ac (kgha)	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Average
		µg/g NO_3-N			
0 (0)	23e				
89 (100)	21e				
178 (200)	116e	29e	29e	35e	31
356 (400)	870cd	40e	133e	521d	231
712 (800)		609d	1220c	1120c	983
1424 (1600)		1010c	2260a	1780b	1690
Average		423	911	865	733

C.V. = 35%

* Individual treatments not followed by a common letter are significantly different at 0.05 probability level by Duncan's Multiple Range Test.

Rates and sources of sludge, rates of NH_4NO_3 and source x rate interaction are significantly different at 0.01 probability level by 'F' test.

TABLE 35. NITRATE-N CONCENTRATION IN CORN STOVER. CAMBRIDGE, 1977.

Nitrogen Rate lb/ac	(kg/ha)	Nitrogen Source: Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average
		$\mu g\ NO_3\text{-}N/g$				
0	(0)	540c*				
89	(100)	530c				
178	(200)	1330abc	420c	570bc	560c	520
356	(400)	2250a	620bc	1160bc	1320abc	1030
712	(800)		1440abc	1000bc	980bc	1140
1424	(1600)		1110bc	1630ab	1630ab	1460
Average			900	1090	1120	1040

C.V. = 51%

* Individual treatments not followed by a common letter are significantly different at the 0.05 probability level by Duncan's Multiple Range Test.

Rates of sludge and NH_4NO_3 are significantly different at 0.01 probability by 'F' test.

TABLE 36. PHOSPHORUS CONCENTRATION IN FIRST CUT (June 8) BROMEGRASS. ELORA, 1977.

Nitrogen Rate lb/ac (kg/ha)		Nitrogen Source				Sludge Average
		Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	
			%P			
0	(0)	0.25ab*				
89	(100)	0.24bcd				
178	(200)	0.22cd	0.26ab	0.24bcd	0.24bcd	0.25
356	(400	0.25abc	0.28a	0.23bcd	0.23bcd	0.25
712	(800)		0.27a	0.21d	0.24bcd	0.24
1424	(1600)		0.28a	0.25abc	0.28a	0.27
Average			0.27	0.23	0.25	0.25

c.v. = 6.5%

* Individual treatments not followed by a common letter are significantly different at 0.05 probability level by Duncan's Multiple Range Test.

Rate and source of sludge are significantly different at 0.01 probability level by 'F' test. Rate of NH_4NO_3 is significant at 0.05 probability level.

TABLE 37. PHOSPHORUS CONCENTRATION IN CORN STOVER. ELORA, 1977.

Nitrogen Rate lb/ac	(kg/ha)	Nitrogen Source Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average
			%P			
0	(0)	0.13abc*				
89	(100)	0.13abc				
178	(200)	0.13abc	0.15a	0.13bc	0.12bc	0.13
356	(400)	0.13abc	0.14ab	0.12bc	0.14ab	0.13
712	(800)		0.12bc	0.11c	0.12bc	0.12
1424	(1600)		0.13abc	0.12bc	0.13abc	0.13
Average			0.13	0.12	0.13	0.13

C.V. = 10%

* Individual treatments not followed by a common letter are significantly different at the 0.05 probability level by Duncan's Multiple Range Test.

Sources of sludge are significantly different at 0.05 probability by 'F' test.

TABLE 38. PHOSPHORUS CONCENTRATION IN CORN STOVER. CAMBRIDGE, 1977.

Nitrogen Rate lb/ac	(kg/ha)	Nitrogen Source				Sludge Average
		Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	
			%P			
0	(0)	0.17ab*				
89	(100)	0.15a-d				
178	(200)	0.16abc	0.17a	0.15a-d	0.15a-d	0.16
356	(400)	0.12cd	0.15a-d	0.12cd	0.13b-d	0.14
712	(800)		0.13bcd	0.12cd	0.12cd	0.12
1424	(1600)		0.13cd	0.12d	0.14a-d	0.13
Average			0.15	0.13	0.13	0.14

C.V. = 15%

* Individual treatments not followed by a common letter are significantly different at the 0.05 probability level by Duncan's Multiple Range Test.

Rates of sludge and rates of NH_4NO_3 are significantly different by 'F' test at 0.01 and 0.05 probability levels respectively.

TABLE 39. SODIUM BICARBONATE-EXTRACTABLE PHOSPHORUS IN SURFACE SOIL (0-6 in). BROMEGRASS EXPERIMENT. FALL, 1977.

Nitrogen Rate	Nitrogen Source				Sludge
lb/ac (kg/ha)	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Average
		µg P/g			
0 (0)	35fgh				
89 (100)	27fgh				
178 (200)	30gh	85de	40fgh	68 ef	64
356 (400)	20h	148c	53e-h	63efg	88
712 (800)		263b	58e-h	87de	136
1424 (1600)		423a	85de	108d	206
Average		230	59	82	124

C.V. = 20%

* Individual treatments not followed by a common letter are significantly different at 0.05 probability level by Duncan's Multiple Range Test.

Rates and sources of sludge, rates of NH_4NO_3 and source x rate interaction are significantly different at 0.01 probability level by 'F' test.

TABLE 40. SODIUM BICARBONATE-EXTRACTABLE PHOSPHORUS IN SURFACE SOIL (0-6 in). CORN EXPERIMENT. ELORA, 1977.

Nitrogen Rate		Nitrogen Source				Sludge Average
lb/ac	(kg/ha)	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	
			µg P/g			
0	(0)	32g*				
89	(100)	53efg				
178	(200)	33g	73def	57efg	60efg	63
356	(400)	40fg	97d	78de	80de	85
712	(800)		193b	83de	105d	127
1424	(1600)		227a	97d	148c	157
Average			148	79	98	108

C.V. = 21%

* Individual treatments not followed by a common letter are significantly different at the 0.05 probability level by Duncan's Multiple Range Test.

Rates and sources of sludge, rates of NH_4NO_3, and source x rate interaction are significantly different at 0.01 probability by 'F' test.

TABLE 41. SODIUM BICARBONATE-EXTRACTABLE PHOSPHORUS IN SURFACE SOIL (0-6in). CORN EXPERIMENT. CAMBRIDGE, 1977.

Nitrogen Rate lb/ac	(kg/ha)	Nitrogen Source				Sludge Average
		Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	
			µg P/g			
0	(0)	93e-h*				
89	(100)	73gh				
178	(200)	62h	127de	92fgh	92fgh	103
356	(400)	93e-h	175c	110ef	100efg	128
712	(800)		217b	123def	153cd	164
1424	(1600)		228a	113ef	150cd	184
Average			202	110	124	145

C.V. = 14%

* Individual treatments not followed by a common letter are significantly different at the 0.05 probability level by Duncan's Multiple Range Test.

Rates and sources of sludge, rates of NH_4NO_3 and source x rate interaction are significantly different by 'F' test at 0.01 probability level.

TABLE 42. POTASSIUM CONCENTRATION IN FIRST CUT (June 8), BROMEGRASS. ELORA, 1977.

Nitrogen Rate lb/ac (kg/ha)		Nitrogen Source				Sludge Average
		Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	
			%K			
0	(0)	1.99b*				
89	(100)	2.00b				
178	(200)	1.98b	2.00b	1.89b	1.85b	1.91
356	(400)	1.81b	2.01b	1.78b	1.79b	1.86
712	(800)		1.79b	1.92b	1.82b	1.84
1424	(1600)		1.74b	2.33a	1.80b	1.96
Average			1.89	1.98	1.82	1.89

C.V. = 8.0%

* Individual treatments not followed by a common letter are significantly different at 0.05 probability level by Duncan's Multiple Range Test.

Rates of ammonium nitrate are significantly different at 0.01 probability level by 'F' test. Source of sludge is significant at 0.05 probability level.

TABLE 43. POTASSIUM CONCENTRATION IN CORN STOVER. ELORA, 1977.

Nitrogen Rate lb/ac	(kg/ha)	Nitrogen Source				Sludge Average
		Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	
			%K			
0	(0)	0.86d*				
89	(100)	0.95cd				
178	(200)	0.96 cd	0.80d	0.99cd	0.99cd	0.93
356	(400)	0.96cd	1.04bcd	1.06bcd	0.95cd	1.01
712	(800)		1.21abc	1.23abc	1.18abc	1.21
1424	(1600)		1.34ab	1.42a	1.26abc	1.34
Average			1.09	1.18	1.09	1.12

C.V. = 15%

* Individual treatments not followed by a common letter are significantly different at the 0.05 probability level by Duncan's Multiple Range Test.

Rates of sludge and NH_4NO_3 are significantly different at 0.01 and 0.05 probability levels, respectively, by 'F' test.

TABLE 44. POTASSIUM CONCENTRATION IN CORN STOVER. CAMBRIDGE, 1977.

Nitrogen Rate lb/ac (kg/ha)	Nitrogen Source				Sludge Average
	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	
	% K				
0 (0)	1.18 cd*				
89 (100)	1.27 bcd				
178 (200)	1.34 bcd	1.06 d	1.60 abc	1.42 a-d	1.36
356 (400)	1.62 ab	1.30 bcd	1.60 abc	1.40 a-d	1.43
712 (800)		1.63 ab	1.45 a-d	1.40 a-d	1.49
1424 (1600)		1.35 bcd	1.56 abc	1.78 a	1.56
Average		1.33	1.55	1.50	1.46

c.v. = 15%

* Individual treatments not followed by a common letter are significantly different at the 0.05 probability level by Duncan's Multiple Range Test.

Rates of NH_4NO_3 are significantly different at 0.05 probability level by 'F' test.

TABLE 45. AMMONIUM ACETATE-EXTRACTABLE POTASSIUM IN SURFACE SOIL (0-6 in). BROMEGRASS EXPERIMENT. FALL, 1977.

Nitrogen Rate		Nitrogen Source				Sludge
lb/ac	(kg/ha)	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Average
			µg K/g			
0	(0)	97a				
89	(100)	77bc				
178	(200)	71c	77bc	72bc	82b	77
356	(400)	69c	70c	73bc	67c	70
712	(800)		67c	69c	71c	69
1424	(1600)		73bc	76bc	73bc	74
Average			72	73	73	73

C.V. = 7.0%

* Individual treatments not followed by a common letter are significantly different at 0.05 probability level by Duncan's Multiple Range Test.

Rates of NH_4NO_3 are significantly different at 0.01 probability level by 'F' test. Rates of sludge are significantly different at 0.05 probability level.

TABLE 46. AMMONIUM ACETATE-EXTRACTABLE POTASSIUM SURFACE SOIL (0-6 in). CORN EXPERIMENT. ELORA, 1977.

Nitrogen Rate lb/ac (kg/ha)	Nitrogen Source				Sludge Average
	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	
		μg K/g			
0 (0)	100 c*				
89 (100)	101 c				
178 (200)	105 c	99 c	112 bc	100 c	104
356 (400)	107 c	107 c	109 bc	108 c	108
712 (800)		107 c	101 c	115 bc	108
1424 (1600)		109 bc	125 ab	133 a	122
Average		105	112	114	111

c.v. = 8.4%

* Individual treatments not followed by a common letter are significantly different at the 0.05 probability level by Duncan's Multiple Range Test.

Rates of sludge are significantly different at 0.01 probability by 'F' test.

TABLE 47. CALCIUM CONCENTRATION IN FIRST CUT (June 8), BROMEGRASS. ELORA, 1977.

Nitrogen Rate lb/ac (kg/ha)		Nitrogen Source				Sludge Average
		Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	
			%Ca			
0	(0)	0.45d*				
89	(100)	0.49bcd				
178	(200)	0.46d	0.45d	0.49cd	0.52bcd	0.49
356	(400)	0.56bcd	0.55bcd	0.56bcd	0.57bcd	0.56
712	(800)		0.67abc	0.62a-d	0.68ab	0.66
1424	(1600)		0.66abc	0.64a-d	0.76a	0.69
Average			0.58	0.58	0.63	0.60

c.v. = 17%

* Individual treatments not followed by a common letter are significantly different at 0.05 probability level by Duncan's Multiple Range Test.

Rates of sludge are significantly different at 0.01 probability level by 'F' test. Rates of ammonium nitrate are significantly different at 0.05 probability level.

TABLE 48. AMMONIUM ACETATE EXTRACTABLE CALCIUM IN SURFACE SOIL (0-6 in). BROMEGRASS EXPERIMENT. FALL, 1977.

Nitrogen Rate lb/ac	(kg/ha)	Nitrogen Source				Sludge Average
		Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	
			µg Ca/g			
0	(0)	2980 e				
89	(100)	3470 de				
178	(200)	2980 e	3900 cd	2900 e	3020 e	3270
356	(400)	2900 e	4300 c	3020 e	2900 e	3410
712	(800)		5200 b	3270 de	2950 e	3810
1424	(1600)		6730 a	3350 de	2770 e	4280
Average			5030	3130	2900	3690

C.V. = 10%

* Individual treatments not followed by a common letter are significantly different at 0.05 probability level by Duncan's Multiple Range Test.

Rates and sources of sludge, rates of NH_4NO_3 and source x rate interaction are significantly different at 0.01 probability level by 'F' test.

TABLE 49. AMMONIUM ACETATE-EXTRACTABLE CALCIUM IN SURFACE SOIL (0-6 in). CORN EXPERIMENT. ELORA, 1977.

Nitrogen Rate lb/ac (kg/ha)	Nitrogen Source				Sludge Average
	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	
		μg Ca/g			
0 (0)	2980 c*				
89 (100)	3480 c				
178 (200)	3120 c	4530 b	2980 c	3470 c	3660
356 (400)	3220 c	4330 b	3430 c	3350 c	3710
712 (800)		5870 a	3330 c	3270 c	4160
1424 (1600)		5830 a	3400 c	3000 c	4090
Average		5140	3330	3270	3900

c.v. = 13%

* Individual treatments not followed by a common letter are significantly different at the 0.05 probability level by Duncan's Multiple Range Test.

Sources of sludge, rates of NH_4NO_3 and source x rate of sludge interaction are significantly different at 0.01 probability level by 'F' test.

TABLE 50. AMMONIUM ACETATE-EXTRACTABLE CALCIUM IN SURFACE SOIL (0-6 in). CORN EXPERIMENT. CAMBRIDGE, 1977.

Nitrogen Rate lb/ac (kg/ha)	Nitrogen Source				Sludge Average
	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	
		μg Ca/g			
0 (0)	2370 def*				
89 (100)	1920 ef				
178 (200)	1800 f	3280 c	2280 def	2100 ef	2560
356 (400)	2320 def	3600 c	2470 de	1900 ef	2660
712 (800)		5370 b	2770 d	2250 def	3460
1424 (1600)		5870 a	2470 de	2000 ef	3440
Average		4530	2500	2060	3030

c.v. = 11%

* Individual treatments not followed by a common letter are significantly different at the 0.05 probability level by Duncan's Multiple Range Test.

Rates of NH_4NO_3, rates and sources of sludge and source x rate interaction are significantly different by 'F' test at 0.01 probability level.

TABLE 51. pH OF SURFACE SOIL (0-6 in). BROMEGRASS EXPERIMENT. FALL, 1977.

Nitrogen Rate		Nitrogen Source				Sludge
lb/ac	(kg/ha)	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Average
0	(0)	7.4bcd				
89	(100)	7.5ab				
178	(200)	7.4bcd	7.7a	7.4bc	7.4bcd	7.5
356	(400)	7.1d	7.8a	7.3bcd	7.2cd	7.4
712	(800)		7.8a	7.3bcd	7.1cd	7.4
1424	(1600)		7.8a	7.3bcd	6.7e	7.3
Average			7.8	7.3	7.1	7.4

C.V. = 2.2%

* Individual treatments not followed by common letter are significantly different at 0.05 probability level by Duncan's Multiple Range Test.

Sources of sludge are significantly different by 'F' test at 0.01 probability level. Rates of sludge and of NH_4NO_3 and source x rate interaction are significantly different at 0.05 probability level.

TABLE 52. pH OF SURFACE SOIL (0-6 in). CORN EXPERIMENT. ELORA, 1977.

Nitrogen Rate lb/ac (kg/ha)	Nitrogen Source				Sludge Average
	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	
0 (0)	7.5 b*				
89 (100)	7.7 a				
178 (200)	7.4 bc	7.9 a	7.5 bc	7.5 b	7.6
356 (400)	7.5 bc	7.9 a	7.5 b	7.4 bcd	7.6
712 (800)		7.9 a	7.4 bcd	7.2 d	7.5
1424 (1600)		7.9 a	7.3 cd	6.8 e	7.3
Average		7.9	7.4	7.2	7.5

c.v. = 1.5%

* Individual treatments not followed by a common letter are significantly different at the 0.05 probability level by Duncan's Multiple Range Test.

Rates and sources of sludge and source x rate interaction are significantly different at 0.01 probability by 'F' test. Rates of NH_4NO_3 are significantly different at 0.05 probability level.

TABLE 53. pH OF SURFACE SOIL (0-6 in). CORN EXPERIMENT. CAMBRIDGE, 1977.

Nitrogen Rate lb/ac (kg/ha)	Nitrogen Source				Sludge Average
	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	
0 (0)	7.5 b*				
89 (100)	7.4 bc				
178 (200)	7.3 bc	7.9 a	7.5 b	7.3 bc	7.6
356 (400)	7.4 b	7.9 a	7.5 b	7.2 c	7.5
712 (800)		7.9 a	7.4 bc	7.3 bc	7.5
1424 (1600)		7.9 a	7.3 bc	6.9 d	7.4
Average		7.9	7.4	7.2	7.5

c.v. = 1.8%

* Individual treatments not followed by a common letter are significantly different at the 0.05 probability level by Duncan's Multiple Range Test.

Sources of sludge are significantly different at 0.01 probability by 'F' test. Rates of NH_4NO_3 are significantly different at 0.05 probability level.

TABLE 54. MAGNESIUM CONCENTRATION IN FIRST CUT (June 8). BROMEGRASS. ELORA, 1977.

Nitrogen Rate lb/ac (kg/ha)	Nitrogen Source				Sludge Average
	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	
		%Mg			
0 (0)	0.15ef*				
89 (100)	0.15ef				
178 (200)	0.17de	0.14f	0.14f	0.16ef	0.15
356 (400)	0.22ab	0.16ef	0.17ef	0.19c	0.17
712 (800)		0.20bc	0.19cd	0.20bc	0.19
1424 (1600)		0.23a	0.19cd	0.23a	0.22
Average		0.18	0.17	0.20	0.18

c.v. = 7.0%

* Individual treatments not followed by a common letter are significantly different at 0.05 probability level by Duncan's Multiple Range Test.

Rates of ammonium nitrate and sludge and source of sludge are significantly different at 0.01 probability level by 'F' test. Source x rate interaction is significant at 0.05 probabiltiy level.

TABLE 55. EFFECT OF SOURCE OF NITROGEN ON MAGNESIUM CONCENTRATION IN CORN STOVER, 1977.

Element	No N	NH_4NO_3	Ca-sludge	Al sludge	Fe-sludge
			% Mg		
			Elora		
Mg*	0.26	0.31	0.26	0.24	0.26
			Cambridge		
Mg*	0.21	0.29	0.25	0.25	0.25

* NH_4NO_3 significantly increased Mg concentration in corn stover by 'F' test at 0.05 probability level.

TABLE 56. AMMONIUM ACETATE-EXTRACTABLE MAGNESIUM IN SURFACE SOIL (0-6 in). BROMEGRASS EXPERIMENT. FALL, 1977.

Nitrogen Rate lb/ac (kg/ha)	Nitrogen Source				Sludge Average
	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	
		μg Mg/g			
0 (0)	370 cde				
89 (100)	330 cde				
178 (200)	460 a	280 ef	340 cde	370 bcd	330
356 (400)	450 ab	300 def	340 cde	375 bcd	340
712 (800)		370 bcd	300 def	390 abc	360
1424 (1600)		340 cde	230 f	350 cde	310
Average		320	300	370	330

C.V. = 13%

* Individual treatments not followed by a common letter are significantly different at 0.05 probability level by Duncan's Multiple Range Test.

Sources of sludge and rates of NH_4NO_3 are significanlty different at 0.01 probability level by "F' test. Source x rate interaction is significant at 0.05 probability level.

TABLE 57. AMMONIUM ACETATE-EXTRACTABLE MAGNESIUM IN SURFACE SOIL (0-6 in). CORN EXPERIMENT AT ELORA, 1977.

Nitrogen Rate lb/ac (kg/ha)	Nitrogen Source				Sludge Average
	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	
			µg Mg/g		
0 (0)	350 bcd*				
89 (100)	300 cde				
178 (200)	390 ab	210 f	350 bcd	320 b-e	290
356 (400)	340 bcd	240 ef	300 cde	360 a-d	300
712 (800)		210 f	290 def	380 abc	290
1424 (1600)		210 f	280 def	440 a	310
Average		220	310	380	300

c.v. = 14%

* Individual treatments not followed by a common letter are significantly different at the 0.05 probability level by Duncan's Multiple Range Test.

Sources of sludge and rates of NH_4NO_3 are significantly different at 0.01 probability level by 'F' test. Source x rate interaction is significant at 0.05 probability.

TABLE 58. MANGANESE CONCENTRATION IN FIRST CUT (June 8). BROMEGRASS. ELORA, 1977.

Nitrogen Rate lb/ac (kg/ha)		Nitrogen Source				Sludge Average
		Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	
			Mn µg/g			
0	(0)	54ab*				
89	(100)	52b				
178	(200)	50b	42cd	41cd	42cd	42
356	(400)	60a	37def	39de	40d	38
712	(800)		31fg	32efg	39de	34
1424	(1600)		29g	31fg	48bc	36
Average			35	36	42	38

C.V. = 9.5%

* Individual treatments not followed by a common letter are significantly different at 0.05 probability level by Duncan's Multiple Range Test.

Rates of sludge and NH_4NO_3, source of sludge and source x rate interaction are significantly different at 0.01 probability level by 'F' test.

TABLE 59. MANGANESE CONCENTRATION IN CORN STOVER. ELORA, 1977.

Nitrogen Rate lb/ac (kg/ha)	Nitrogen Source				Sludge Average
	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	
			µg Mn/g		
0 (0)	32 bc*				
89 (100)	36 abc				
178 (200)	38 abc	41 ab	34 bc	30 c	35
356 (400)	45 a	39 abc	36 abc	35 abc	37
712 (800)		35 bc	35 abc	35 bc	35
1424 (1600)		37 abc	36 abc	39 abc	37
Average		38	35	35	36

c.v. = 14%

* Individual treatments not followed by a common letter are significantly different at the 0.05 probability level by Duncan's Multiple Range Test.

Rates of NH_4NO_3 are significantly different at 0.05 probability by 'F' test.

TABLE 60. BORON CONCENTRATION IN FIRST CUT (June 8). BROMEGRASS. ELORA, 1977.

Nitrogen Rate lb/ac (kg/ha)	Nitrogen Source				Sludge Average
	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	
		B ug/g			
0 (0)	10.0a*				
89 (100)	10.0a				
178 (200)	9.3abc	9.7ab	9.7ab	9.3abc	9.6
356 (400)	9.3abc	9.0bc	10.0a	9.0bc	9.3
712 (800)		9.0bc	8.7c	9.0bc	8.9
1424 (1600)		9.7ab	9.0bc	9.0bc	9.2
Average		9.3	9.3	9.1	9.3

c.v. = 4.7%

* Individual treatments not followed by a common letter are significantly different at 0.05 probability level by Duncan's Multiple Range Test.

Rates of ammonium nitrate are significantly different at 0.01 probability level by 'F' test. Rates of sludges are significantly different at 0.05 probability level.

TABLE 61. CADMIUM CONCENTRATION IN FIRST CUT (June 8). BROMEGRASS. ELORA, 1977.

Nitrogen Rate lb/ac	(kg/ha)	Nitrogen Source				Sludge Average
		NH_4NO_3	Calcium Sludge	Aluminum Sludge	Iron Sludge	
			Cd ug/g			
0	(0)	0.07de*				
89	(100)	0.07de				
178	(200)	0.07de	0.05e	0.10cde	0.07de	0.07
356	(400)	0.10cde	0.05e	0.08cde	0.12cd	0.08
712	(800)		0.07de	0.13bc	0.17ab	0.12
1424	(1600)		0.08 cde	0.18a	0.20a	0.16
Average			0.06	0.13	0.14	0.11

c.v. = 28%

* Individual treatments not followed by a common letter are significantly different at 0.05 probability level by Duncan's Multiple Range test.

Rates and sources of sludge, and rates of NH_4NO_3 are significantly different at 0.01 probability level by 'F' test. Source x rate interaction is significant at 0.05 probability level.

TABLE 62. CADMIUM CONCENTRATION IN CORN STOVER. ELORA, 1977.

Nitrogen Rate lb/ac (kg/ha)		Nitrogen Source				Sludge Average
		Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	
			μg Cd/g			
0	(0)	0.15f*				
89	(100)	0.21ef				
178	(200)	0.22 def	0.23def	0.34cde	0.25def	0.27
356	(400)	0.23def	0.25def	0.42bc	0.37cd	0.35
712	(800)		0.28c-f	0.54b	0.41bc	0.41
1424	(1600)		0.35cde	0.77a	0.53b	0.55
Average			0.28	0.52	0.39	0.39

C.V. = 23%

* Individual treatments not followed by a common letter are significantly different at the 0.05 probability level by Duncan's Multiple Range Test.

Rates and sources of sludge and source x rate interaction are significantly different at 0.01 probability level by 'F' test.

TABLE 63. CADMIUM CONCENTRATION IN CORN STOVER. CAMBRIDGE, 1977.

Nitrogen Rate lb/ac (kg/ha)		Nitrogen Source				Sludge Average
		Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	
			µg Cd/g			
0	(0)	0.26e				
89	(100)	0.37de				
178	(200)	0.28e	0.36de	0.44cde	0.68bcd	0.49
356	(400)	0.43cde	0.32e	0.50cde	0.37de	0.40
712	(800)		0.32e	1.12a	0.59cde	0.68
1424	(1600)		0.44cde	0.90ab	0.72bc	0.69
Average			0.36	0.74	0.59	0.56

C.V. = 34%

* Individual treatments not followed by a common letter are significantly different at the 0.05 probability level by Duncan's Multiple Range Test.

Rates and sources of sludge, rates of NH_4NO_3, and source x rate interaction are significantly different at 0.01 probability level by 'F' test.

TABLE 64. METAL CONTENT OF CORN GRAIN FROM SELECTED TREATMENTS, ELORA AND CAMBRIDGE, 1977.

Element	Source of Nitrogen					C.V. %
	Ammonium Nitrate		Calcium Sludge	Alum Sludge	Iron Sludge	
	N rate - lb/ac (kg/ha)					
	89 (100)	356 (400)	1424 (1600)	1424 (1600)	1424 (1600)	
	µg/g					
	Elora					
Cd	0.06*	0.05	0.06	0.06	0.06	28
Cr	0.32	0.41	0.39	0.32	0.36	34
Cu	1.3 b	3.0 a	1.7 b	2.3 ab	2.0 ab	32
Mn	5.0	4.3	5.3	7.3	4.0	65
Ni	0.30 b	0.33 b	0.75 a	0.36 b	0.33 b	19
Zn	22	21	28	29	28	22
	Cambridge					
Cd	0.06	0.06	0.06	0.09	0.06	30
Cr	0.20	0.27	0.23	0.23	0.25	24
Cu	2.0	2.3	1.7	2.7	2.3	24
Mn	4.3 b	7.3 a	4.7 b	4.0 b	6.0 ab	24
Ni	0.21 b	0.27 b	0.99 a	0.33 b	0.30 b	31
Zn	21 b	29 ab	26 ab	29 ab	34 a	20

* Individual values for an element not followed by a common letter are significantly different at 0.05 probability level by Duncan's Multiple Range Test. Individual rows without letters after each value indicate that treatment differences were not significant. Pb values for both experiments were not presented being less than 0.30 ppm (detection limit) as were B values which were less than 2.0 ppm (detection limit).

TABLE 65. CADMIUM CONCENTRATION IN FIRST CUT OF BROMEGRASS FROM SELECTED TREATMENTS FROM 1973 TO 1977 INCLUSIVE.

	Nitrogen Source				
	NH_4NO_3		Lime Sludge	Alum Sludge	Iron Sludge
Year	100 kg N/ha	400 kg N/ha	1600 kg N/ha	1600 kg N/ha	1600 kg N/ha
			µg Cd/g		
1973[§]	0.16 b*	0.17 ab	0.23 ab	0.25 a	0.21 ab
1974[†]	0.05	0.10	0.07	0.10	0.12
1975	0.09 c	0.13 c	0.10 c	0.14 bc	0.37 a
1976	0.05 g	0.09 c	0.07 c-f	0.08 cd	0.23 a
1977	0.07 de	0.10 cde	0.08 cde	0.18 a	0.20 a

* Individual treatments for a given year not followed by a common letter are significantly different at 0.05 probability level by Duncan's Multiple Range Test.

§ Data from third cut.

† No statistical analysis was possible because a number of samples had lower than detection limits of Cd.

TABLE 66. CADMIUM CONCENTRATION IN CORN STOVER FROM ELORA AND CAMBRIDGE FROM 1973 TO 1977 INCLUSIVE.

Year	Nitrogen Source				
	NH_4NO_3		Lime Sludge	Alum Sludge	Iron Sludge
	100 kg N/ha	400 kg N/ha	1600 kg N/ha	1600 kg N/ha	1600 kg N/ha
			µg Cd/g		
			Elora		
1973	0.23 b*	0.28 ab	0.30 ab	0.40 a	0.38 a
1974	0.28 abc	0.31 abc	0.37 abc	0.46 ab	0.54 a
1975	0.24 d	0.43 cd	0.43 cd	0.67 ab	0.80 a
1976	0.30 def	0.33 def	0.43 cde	0.67 a	0.70 a
1977	0.21 ef	0.23 def	0.35 cde	0.77 a	0.53 b
			Cambridge		
1973	0.38 b	0.58 a	0.60 a	0.39 b†	0.64 a
1974	0.35 c	0.59 bc	0.85 ab	0.43 bc	1.11 a
1975	0.50 bc	0.78 a	0.55 abc	0.46 bc	0.42 bc
1976	0.43 fg	0.70 c-f	0.63 c-g	1.03 ab	1.13 a
1977	0.37 de	0.43 cde	0.44 cde	0.90 ab	0.72 bc

* Individual treatments for a given year and site which are not followed by a common letter are significantly different at 0.05 probability level by Duncan's Multiple Range Test.

† No alum sludge was applied at this rate in 1973 because the length of time required to dry the plots would have delayed planting.

TABLE 67. CHROMIUM CONCENTRATION IN FIRST CUT (June 8). BROMEGRASS. ELORA, 1977.

Nitrogen Rate lb/ac (kg/ha)		Nitrogen Source				Sludge Average
		Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	
			Cr ug/g			
0	(0)	0.7abc*				
89	(100)	1.0abc				
178	(200)	0.7abc	1.0ab	0.7abc	0.6bc	0.8
356	(400)	0.6abc	1.2a	0.8abc	0.4c	0.8
712	(800)		0.7abc	1.0abc	0.7abc	0.8
1424	(1600)		0.8abc	1.1ab	0.9abc	0.9
Average			0.9	0.9	0.6	0.8

c.v. = 38%

* Individual treatments not followed by a common letter are significantly different at 0.05 probability level by Duncan's Multiple Range Test.

TABLE 68. CHROMIUM CONCENTRATION IN CORN STOVER. CAMBRIDGE, 1977.

Nitrogen Rate lb/ac (kg/ha)	Nitrogen Source				Sludge Average
	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	
		µg Cr/g			
0 (0)	1.4 cd				
89 (100)	1.4 cd				
178 (200)	1.0d	1.6bcd	1.7bcd	1.4bcd	1.6
356 (400)	1.3cd	2.2ab	1.7bcd	1.3d	1.7
712 (800)		1.4bcd	2.6a	1.3cd	1.8
1424 (1600)		1.6bcd	2.1abc	1.3cd	1.7
Average		1.7	2.0	1.3	1.7

C.V. = 25%

* Individual treatments not followed by a common letter are significantly different at the 0.05 probability level by Duncan's Multiple Test.

Sources of sludge are significantly different by 'F' test at 0.01 probability level. Rate of NH_4NO_3 and source x rate interaction are significantly different at 0.05 probability level.

TABLE 69. COPPER CONCENTRATION IN FIRST CUT (June 8). BROMEGRASS. ELORA, 1977.

Nitrogen Rate lb/ac (kg/ha)	Nitrogen Source				Sludge Average
	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	
		Cu ug/g			
0 (0)	5.7j*				
89 (100)	6.3ij				
178 (200)	7.3ghi	6.3ij	7.0hij	7.0hij	6.8
356 (400)	8.3e-h	7.7f-i	9.0c-f	9.7b-e	8.8
712 (800)		8.7d-g	10.7ab	9.7b-e	9.7
1424 (1600)		10.0bcd	11.7a	10.3abc	10.7
Average		8.2	9.6	9.2	9.0

c.v. = 10%

*Individual treatments not followed by a common letter are significantly different at 0.05 probability level by Duncan's Multiple Range Test.

Rates of ammonium nitrate and sludge and sources of sludge are significantly different at 0.01 probability level by 'F' test.

TABLE 70. COPPER CONCENTRATION IN CORN STOVER. ELORA, 1977.

Nitrogen Rate lb/ac	(kg/ha)	Nitrogen Source: Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average
		μg Cu/g				
0	(0)	4.8c*				
89	(100)	8.7ab				
178	(200)	8.2b	9.3ab	8.8ab	8.8ab	9.0
356	(400)	8.7ab	9.5ab	10.3ab	9.3ab	9.7
712	(800)		9.5ab	10.7a	9.8ab	10.0
1424	(1600)		9.2ab	10.4ab	10.5a	10.0
Average			9.4	10.1	9.6	9.7

C.V. = 12%

* Individual treatments not followed by a common letter are significantly different at the 0.05 probability level by Duncan's Multiple Range Test.

TABLE 71. COPPER CONCENTRATION IN CORN STOVER. CAMBRIDGE, 1977.

Nitrogen Rate lb/ac (kg/ha	Nitrogen Source				Sludge Average
	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	
		µg Cu/g			
0 (0)	6.5d				
89 (100)	11.7abc				
178 (200)	11.8abc	10.7bc	12.8abc	10.2c	11.2
356 (400)	12.0abc	10.2bc	11.5abc	11.2abc	10.9
712 (800)		13.5ab	14.0a	11.3abc	12.9
1424 (1600)		10.5bc	12.3abc	11.5abc	11.4
Average		11.2	12.7	11.0	11.6

C.V. = 14%

* Individual treatments not followed by a common letter are significantly different at the 0.05 probability level by Duncan's Multiple Range Test.

Rates of NH_4NO_3 are signicantly different at 0.01 probability by 'F' test. Sources of sludge are significantly different at 0.05 probability.

TABLE 72. COPPER CONCENTRATIONS IN FIRST CUT OF BROMEGRASS FROM SELECTED TREATMENTS FROM 1973 TO 1977 INCLUSIVE.

Year	Nitrogen Source				
	NH_4NO_3		Lime Sludge	Alum Sludge	Iron Sludge
	100 kg N/ha	400 kg N/ha	1600 kg N/ha	1600 kg N/ha	1600 kg N/ha
			μg Cu/g		
1973 §	5.7 c*	10.3 b	16.0 a	11.0 ab	13.0 b
1974	7.7 ef	8.3 c-f	10.0 abc	11.3 a	10.3 ab
1975	8.7 d-h	11.3 bcd	13.3 ab	15.0 a	14.7 a
1976	8.0 ef	8.7 def	12.0 ab	12.3 ab	13.7 a
1977	6.3 ij	8.3 e-h	10.0 bcd	11.7 a	10.3 abc

* Individual treatments for a given year not followed by a common letter are significantly different at 0.05 probability level by Duncan's Multiple Range Test.

§ Data from third cut.

TABLE 73. COPPER CONCENTRATIONS IN CORN STOVER FROM ELORA AND CAMBRIDGE, 1973 TO 1977 INCLUSIVE.

Year	Nitrogen Source				
	NH_4NO_3		Lime Sludge	Alum Sludge	Iron Sludge
	100 kg N/ha	400 kg N/ha	1600 kg N/ha	1600 kg N/ha	1600 kg N/ha
			µg Cu/g		
			Elora		
1973	7.0 a*	5.3 a	8.3 a	9.3 a	10.3 a
1974	6.7 b	9.0 ab	11.3 ab	11.7 ab	11.7 ab
1975	9.7 ab	9.6 ab	8.9 abc	8.5 bc	9.9 ab
1976	5.3 ab	6.7 a	6.3 a	7.0 a	6.7 a
1977	8.7 ab	8.7 ab	9.2 ab	10.4 ab	10.5 a
			Cambridge		
1973	10.3 b-f	11.0 a-d	11.7 ab	9.3 def**	12.7 f
1974	8.3 cd	11.0 abc	10.3 a-d	12.0 ab	12.3 a
1975	8.3 ab	8.7 ab	9.3 ab	8.8 ab	8.5 ab
1976	7.7 bc	8.3 bc	8.0 bc	9.3 ab	11.0 a
1977	11.7 abc	12.0 abc	10.5 bc	12.3 abc	11.5 abc

* Individual treatments for a given year and site which are not followed by a common letter are significantly different at 0.05 probability level by Duncan's Multiple Range Test.

** No alum sludge was applied at this rate in 1973 in Cambridge because the length of time required to dry the plots would have delayed planting.

TABLE 74. NICKEL CONCENTRATION IN FIRST CUT (June 8). BROMEGRASS. ELORA, 1977.

Nitrogen Rate lb/ac (kg/ha)	Nitrogen Source				Sludge Average
	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	
		Ni ug/g			
0 (0)	0.8e*				
89 (100)	0.8e				
178 (200)	0.8e	2.6c	0.9e	0.7e	1.4
356 (400)	0.7e	3.5c	0.8e	0.8e	1.7
712 (800)		4.7b	1.1de	0.6e	2.1
1424 (1600)		6.0a	1.7d	1.1de	2.9
Average		4.2	1.1	0.8	2.0

c.v. = 14%

* Individual treatments not followed by a common letter are significantly different at 0.05 probability level by Duncan's Multiple Range Test.

Rates of sludge and NH_4NO_3 and sources of sludge are significantly different at 0.01 probability level by 'F' test. Source x rate interaction is significant at 0.05 probability level.

TABLE 75. NICKEL CONCENTRATION IN CORN STOVER. ELORA, 1977.

Nitrogen Rate lb/ac (kg/ha)	Nitrogen Source				Sludge Average
	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	
		μg Ni/g			
0 (0)	0.9c				
89 (100)	0.8c				
178 (200)	0.7c	1.9b	0.8c	0.7c	1.1
356 (400)	0.8c	3.5a	1.0c	0.8c	1.8
712 (800)		2.9ab	0.9c	0.8c	1.5
1424 (1600)		2.3ab	0.8c	0.9c	1.3
Average		2.6	0.8	0.8	1.4

C.V. = 52%

* Individual treatments not followed by a common letter are significantly different at the 0.05 probability level by Duncan's Multiple Range Test.

Sources of sludge are significantly different at 0.01 probability level by 'F' test.

TABLE 76. NICKEL CONCENTRATION IN CORN STOVER. CAMBRIDGE, 1977.

Nitrogen Rate lb/ac (kg/ha)		Nitrogen Source				Sludge Average
		Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	
			µg Ni/g			
0	(0)	1.0cd				
89	(100)	1.1cd				
178	(200)	0.9d	1.9abc	1.0cd	1.0d	1.3
356	(400)	1.0cd	3.2a	1.0cd	0.9d	1.7
712	(800)		1.6bcd	1.2cd	0.8d	1.2
1424	(1600)		2.5ab	1.0cd	0.8d	1.4
Average			2.3	1.0	0.9	1.4

C.V. = 53%

* Individual treatments not followed by a common letter are significantly different at the 0.05 probability level by Duncan's Multiple Range Test.

Sources of sludge are significantly different at 0.01 probability level by 'F' test.

TABLE 77. NICKEL CONCENTRATIONS IN FIRST CUT OF BROMEGRASS FROM SELECTED TREATMENTS FROM 1973 TO 1977 INCLUSIVE.

Year	Nitrogen Source				
	NH_4NO_3		Lime Sludge	Alum Sludge	Iron Sludge
	100 kg N/ha	400 kg N/ha	1600 kg N/ha	1600 kg N/ha	1600 kg N/ha
			µg Ni/g		
1973[§]	1.3 b	1.0 ab	1.5 b	0.5 a	1.1 ab
1974	1.3 a	1.7 a	1.2 a	1.8 a	1.5 a
1975	1.3 a	2.1 a	1.2 a	1.9 a	1.6 a
1976	0.5 a	0.5 a	0.6 a	1.1 ab	0.5 a
1977	0.8 e	0.7 e	6.0 a	1.7 b	1.1 de

* Individual treatments for a givenyear not followed by a common letter are significantly different at 0.05 probability level by Duncan's Multiple Range Test.

[§] Data from third cut.

TABLE 78. NICKEL CONCENTRATIONS IN CORN STOVER FROM ELORA AND CAMBRIDGE 1973 TO 1977 INCLUSIVE.

Year	Nitrogen Source				
	NH_4NO_3		Lime Sludge	Alum Sludge	Iron Sludge
	100 kg N/ha	400 kg N/ha	1600 kg N/ha	1600 kg N/ha	1600 kg N/ha
			µg Ni/g		
			Elora		
1973	1.5a	1.3a	1.2a	1.3a	0.8a
1974	0.9a	1.3a	1.5a	-	1.9a
1975	1.9a	1.1ab	1.5ab	1.0ab	0.9ab
1976	0.6abc	0.6abc	0.5abc	0.7abc	0.6abc
1977	0.8c	0.8c	2.3ab	0.8c	0.9c
			Cambridge		
1973	1.4a	1.4a	1.5a	1.8a†	1.1a
1974	1.6ab	1.7ab	1.3ab	2.3ab	1.4ab
1975	1.5a	1.5a	1.6a	1.0a	1.3a
1976	0.9cd	0.7d	2.0a	1.2bc	0.9cd
1977	1.1cd	1.0cd	2.5ab	1.0cd	0.8d

* Individual treatments for a given year and site which are not followed by a common letter are significantly different at 0.05 probability level by Duncan's Multiple Range Test.

† No alum sludge was applied at this rate in 1973 because the length of time required to dry the plots would have delayed planting.

TABLE 79. LEAD CONCENTRATION IN FIRST CUT (June 8). BROMEGRASS. ELORA, 1977.

Nitrogen Rate lb/ac (kg/ha)		Nitrogen Source				Sludge Average
		Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	
			Pb ug/g			
0	(0)	0.8c*				
89	(100)	1.0bc				
178	(200)	0.8bc	1.0bc	1.0bc	1.1bc	1.0
356	(400)	1.1bc	1.2bc	1.3abc	1.2bc	1.2
712	(800)		0.9bc	1.2bc	1.3bc	1.1
1424	(1600)		0.9bc	1.8a	1.4ab	1.4
Average			1.0	1.3	1.2	1.2

c.v. = 25%

* Individual treatments not followed by a common letter are significantly different at 0.05 probability level by Duncan's Multiple Range Test.

Rates of ammonium nitrate and sources of sludge are significantly different at 0.05 probability level by 'F' test.

TABLE 80. ZINC CONCENTRATION IN FIRST CUT (June 8). BROMEGRASS. ELORA, 1977.

Nitrogen Rate lb/ac (kg/ha)		Nitrogen Source				Sludge Average
		Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	
			Zn ug/g			
0	(0)	14g*				
89	(100)	14g				
178	(200)	18f	17fg	19f	18f	18
356	(400)	22de	19f	23de	23de	22
712	(800)		22e	28bc	28bc	26
1424	(1600)		25cd	30b	34a	30
Average			21	25	26	24

C.V. = 8.1%

* Individual treatments not followed by a common letter are significantly different at 0.05 probability level by Duncan's Multiple Range Test.

Rates of sludge and NH_4NO_3 and sources of sludge are significantly different at 0.01 probability level by 'F' test. Source x rate interaction is sig nificant at 0.05 probability level.

TABLE 81. ZINC CONCENTRATION IN CORN STOVER. ELORA, 1977.

Nitrogen Rate lb/ac	(kg/ha)	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average
			μg Zn/g			
0	(0)	19g*				
89	(100)	18g				
178	(200)	18g	34efg	39d-g	29fg	34
356	(400)	20g	34efg	47def	44def	42
712	(800)		54cde	104ab	67b-e	75
1424	(1600)		67bcd	106a	83abc	86
Average			47	74	56	59

C.V. = 45%

* Individual treatments not followed by a common letter are significantly different at the 0.05 probability level by Duncan's Multiple Range Test.

Rates and sources of sludge and rates of NH_4NO_3 are significantly different at 0.01 probability level by 'F' test.

TABLE 82. ZINC CONCENTRATION IN CORN STOVER. CAMBRIDGE, 1977.

Nitrogen Rate lb/ac (kg/ha)	Nitrogen Source				Sludge Average
	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	
		μg Zn/g			
0 (0)	40g				
89 (100)	50def				
178 (200)	66def	49fg	72cd	58d-g	59
356 (400)	67def	50efg	79bcd	67def	65
712 (800)		69cde	100b	89bc	86
1424 (1600)		96b	157a	103b	119
Average		66	102	79	82

C.V. = 16%

* Individual treatments not followed by a common letter are significantly different at the 0.05 probability level by Duncan's Multiple Range Test.

Rates and sources of sludge and rates of NH_4NO_3 are significantly different at 0.01 probability levels by "F' test.

TABLE 83. ZINC CONCENTRATIONS IN FIRST CUT OF BROMEGRASS FROM SELECTED TREATMENTS FROM 1973 TO 1977 INCLUSIVE.

Year	Nitrogen Source				
	NH_4NO_3		Lime Sludge	Alum Sludge	Iron Sludge
	100 kg N/ha	400 kg N/ha	1600 kg N/ha	1600 kg N/ha	1600 kg N/ha
			µg Zn/g		
1973§	19c*	26b	33a	26b	31a
1974	19f	22de	28ab	29ab	28ab
1975	17fg	30bc	30bc	33b	41a
1976	15e	20cde	25bc	24bcd	39a
1977	14g	22de	25cd	30b	34a

* Individual treatments for a given year not followed by a common letter are significantly different at 0.05 probability level by Duncan's Multiple Range Test.

§ Data from third cut.

TABLE 84. ZINC CONCENTRATIONS IN CORN STOVER FROM ELORA AND CAMBRIDGE, 1973 TO 1977 INCLUSIVE.

Year	Nitrogen Source				
	MH_4NO_3		Lime Sludge	Alum Sludge	Iron Sludge
	100 kg N/ha	400 kg N/ha	1600 kg N/ha	1600 kg N/ha	1600 kg N/ha
			µg Zn/g		
			Elora		
1973	19 cd*	18 d	30 b-d	37 a-d	41 ab
1974	15 i	22 f-i	36 cde	54 b	89 a
1975	18 e	23 e	55 bc	72 b	106 a
1976	15 e	20 de	62 ab	69 a	88 a
1977	18 g	20 g	67 bcd	106 a	83 abc
			Cambridge		
1973	64 c	96 bc	137 a	53** c	111 ab
1974	47 fg	80 d-g	151 a	133 abc	135 ab
1975	55 bc	117 abc	124 ab	131 a	77 abc
1976	45 hi	65 d-h	76 cde	124 ab	137 a
1977	50 fg	67 def	96 b	157 a	103 a

* Individual treatments for a given year and site which are not followed by a common letter are significantly different at 0.05 probability level by Duncan's Multiple Range Test.

** No alum sludge was applied at this rate in Cambridge in 1973 because the length of time required to dry the plots would have delayed planting.

TABLE 85. CONCENTRATIONS OF ANTIMONY, COBALT, MERCURY, MOLYBDENUM AND SELENIUM IN FIRST CUT OF BROMEGRASS FROM SELECTED TREATMENTS (June 8, 1977)

Element	Source and rate of N (kg N/ha)				
	NH_4NO_3		Ca-sludge	Al-sludge	Fe-sludge
	200	400	1600	1600	1600
	μg/g				
Sb	0.11	0.11	0.12	0.12	0.13
Co	0.04	0.04	0.05	0.04	0.05
Hg	0.032	0.030	0.034	0.034	0.035
Mo	0.33	0.33	1.03	0.74	0.50
Se	0.04	0.04	0.03	0.03	0.05

TABLE 86. ANTIMONY, COBALT, MERCURY, MOLYBDENUM AND SELENIUM CONCENTRATIONS IN CORN GRAIN AND STOVER FROM SELECTED TREATMENTS, 1977.

Metal	Source and rate of N (kg N/ha)				
	NH_4NO_3		Ca-sludge	Al-sludge	Fe-sludge
	100	400	1600	1600	1600
	μg/g				
			Elora, grain		
Sb	0.02	<0.01	<0.01	<0.01	<0.01
Co	0.06	0.07	0.07	0.06	0.06
Hg	0.015	0.015	0.015	0.013	0.014
Mo	0.10	0.05	0.24	0.14	0.10
Se	0.02	0.02	0.01	0.02	0.01
			Elora, stover		
Sb	0.11	0.03	0.17	0.03	0.12
Co	0.09	0.07	0.08	0.06	0.09
Hg	0.034	0.037	0.038	0.035	0.033
Mo	0.17	0.20	0.24	0.20	0.15
Se	0.01	0.04	0.02	0.02	0.01
			Cambridge, grain		
Sb	<0.01	0.01	<0.01	<0.01	<0.01
Co	0.07	0.06	0.06	0.07	0.06
Hg	0.011	0.012	0.013	0.012	0.012
Mo	0.28	0.28	0.35	0.21	0.26
Se	<0.02	<0.03	<0.03	<0.03	<0.04
			Cambridge, stover		
Sb	0.03	<0.01	0.03	0.03	0.03
Co	0.13	0.12	0.11	0.12	0.08
Hg	0.039	0.033	0.039	0.038	0.034
Mo	0.35	0.46	0.79	0.28	0.54
Se	0.03	0.03	0.02	0.02	0.03

TABLE 87. NTA-EXTRACTABLE CADMIUM, COPPER, NICKEL AND ZINC FROM SURFACE SOIL (0-6 in), NOVEMBER, 1977.

Metal	Treatment (Source and rate of N, kg N/ha)						
	NH_4NO_3	Ca-sludge		Al-sludge		Fe-sludge	
	100 (200)†	200(400)	1600(1600)	200(400)	1600(1600)	200(400)	1600(1600)
	µg/g						
	Bromegrass						
Cd	0.32d*	0.38d	0.53cd	1.03b	2.46a	0.69c	1.34b
Cu	3.5 e	12.2 d	26.6 b	18.5 c	52.5 a	20.8 bc	52.5 a
Ni	1.3 d	17.5 b	44.5 a	1.7 d	5.2 c	1.8 d	3.0 cd
Zn	7 e	50 cd	111 b	77 c	249 a	44 d	114 b
	Corn, Elora						
Cd	0.27de	0.19e	0.28de	0.69c	1.61a	0.37d	1.13b
Cu	3.9 f	7.6 e	20.6 c	13.0 d	33.3 b	10.5 b	46.3 a
Ni	0.9 d	5.4 b	27.8 a	1.2 d	2.7c	1.7 d	1.5 d
Zn	9 e	25 d	89 b	44 c	156 a	24 d	92 b
	Corn, Cambridge						
Cd	0.41d	0.29d	0.21e	0.69c	2.01a	0.75c	1.23b
Cu	12.1 c	12.3 c	16.1 bc	18.6 b	42.5 a	20.0 b	46.7 a
Ni	1.2 d	7.1 b	16.1 a	1.1 d	3.3 c	0.9 d	1.8 d
Zn	23 d	42 c	57 c	58 c	218 a	40 c	92 b

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* Individual values in any one row followed by a common letter are not significantly different at 0.05 probability by Duncan's Multiple Range test.

† Rate of N in parentheses are those for the bromegrass experiment.

5. GREENHOUSE EXPERIMENT

5.1 Objectives

1) To determine the effects of various sewage sludges on crop growth.
2) To determine the effects of metals in sewage sludge or metal uptake by plants.

5.2 Materials and Methods

Nine Ontario sludges were applied to a Grimsby sandy loam soil in pots and ryegrass was grown. Sludge was applied before seeding of each crop, at 178, 712 and 1424 lb N/ac (200, 800 and 1600 kg N/ha) per application. A total of five crops of ryegrass were grown and harvested up to March 1976.

After the fifth crop was harvested, the soils were limed to approximately pH 6.5, if required, and three of the nine sludges were dropped from the experiment. The six sludges retained were chosen because of their high metal content and were added to only half the pots in each treatment before seeding each crop. To the other half of the pots in each treatment, no further sludge applications were made. Six more crops of ryegrass were grown (6th, 7th, 8th, 9th, 10th and 11th). Dates when various operations were performed and rates of fertilizers added are presented in Table 88. The results for crops one to eight were presented in previous reports entitled "Land Disposal of Sewage Sludge", Volumes III, IV and V, Research Reports No. 25, 60 and 73.

5.3 Results and Discussion

Chemical analyses of sludges applied to the 9th, 10th and 11th crops are presented in Tables 89, 90 and 91. The amounts of nutrients and metals added in the sludges in the 9th, 10th and 11th applications are presented in Tables 92, 93 and 94. The total amounts up to the 9th, 10th and 11th applications are presented in Tables 95, 96 and 97. In computing these values, it was assumed that a hectare of soil (15 cm deep) contained 2.24 x 10^6 kg of soil. The weight of soil per pot was 3 kg.

To reduce salinity problems, the pots were leached following the 3rd, 5th, 7th, 9th and 11th applications of sludge. The concentrations and total amounts of nutrients and metals leached from selected treatments are shown in Tables 98, 99, 100 and 101. Only small proportions of the metals added were removed in the leachates.

Dry matter yields of the 9th, 10th and 11th crops of ryegrass are presented in Tables 102, 103 and 104. Ammonium nitrate produced higher yields in the 9th crop but lower in the 10th and 11th crops than were obtained with sewage sludge. Yields of treatments continuing to receive the Fergus sludge at high rates were drastically reduced. This effect was less marked in crops 9 and 11, probably because all treatments were leached before the 9th and 11th crops. Yields were low in the 10th crop where 1600 kg N from sludge was added only for the first five crops. This is believed to be due to nitrogen deficiency as no nitrogen was added after the fifth crop (Table 88). The low nitrogen content in the grass in the 10th crop, compared to crops 9 and 11, confirms that nitrogen deficiency did occur in that treatment (Tables 105, 106 and 107).

Nitrogen concentration in ryegrass was relatively low where the lowest rate of sludge was applied and this may have had some effect on yield.

Soil pH was adjusted by adding calcium carbonate to treatments requiring it in an effort to maintain pH at 6.5 or higher. The control and treatments receiving Fergus and North Toronto sludges were not maintained at the desired level, however (Table 108).

Phosphorus concentrations in the ryegrass were quite high in all treatments (Table 109) and bore no relation to the phosphorus supplied in sludges.

Potassium concentrations in the 9th and 10th crops are presented in Tables 110 and 111. Concentrations increased with rate of sludge but do not appear to be related to differences in amounts added due to the source of sludge (Table 110).

Calcium concentrations were relatively high and did not appear to be related to amounts added in sludges (Table 112). With few exceptions, sludge treatments reduced plant calcium in comparison with the check treatment.

Magnesium concentrations were quite high, particularly where the Midland sludge, which supplied the most magnesium, continued to be added at high rates (Table 113).

Manganese concentrations were quite high with treatments receiving the Fergus and North Toronto sludges (Tables 114 and 115). This is believed to be caused by the lower soil pH values (Table 108) with those two sludges.

Iron concentrations for the 9th and 10th crops are presented in Tables 116 and 117. Treatment differences are not readily explained.

Boron concentrations continued to be highest with the Midland sludge, which supplied the most boron (Tables 118 and 119).

Cadmium concentrations in the 9th, 10th and 11th crops of ryegrass are presented in Tables 120, 121 and 122. Cadmium concentration in the ryegrass from the check treatment was higher or as high as that from the sludge treatments with the exception of the Guelph, and in the 11th crop from the Sarnia sludge. The high cadmium concentration with the check may be due to the low soil pH (Table 108). It is also possible that the low cadmium sludges reduced the availability of soil cadmium. The Guelph and Sarnia sludges supplied much more cadmium than the other sludges. Stoppage of application of the Sarnia sludge to half of the pots after the fifth crop reduced the Cd concentrations in ryegrass in the 9th, 10th and 11th crops. Omission of Guelph sludge in the 6th and later crops resulted in cadmium concentrations that were higher than in ryegrass that had continued to receive sludge applications. A similar trend was observed in the 9th and 11th crops with all the sludges except that from Sarnia (Tables 120 and 122). Cadmium concentrations in all eleven crops of ryegrass receiving the Guelph and North Toronto sludges are presented in Table 123. There was a tendency for cadmium concentration in the ryegrass to increase slightly from crop to crop but this tendency was present in the control treatment as well as in those receiving sludges, and cannot be attributed to the increasing cadmium content of the soil from crop to crop. Increased cadmium in the control cannot be explained at this time. The pattern of lower cadmium content in the 3rd, 5th, 7th, 9th and 11th crops after leaching is not consistent.

Chromium concentration in the 9th crop of ryegrass is presented in Table 124. Chromium content increased with increasing rate of sludge application. Where sludge application had been stopped at the 5th crop the chromium concentration in the 9th crop of ryegrass was lower with some sludges and higher with others than where sludge application had been continued.

Copper concentrations in the ryegrass increased with sludge application rate (Table 125, 126 and 127). Treatments receiving the Fergus sludge had very high concentrations of plant copper, particularly where high rates of sludge were applied. The severe depression of yield caused by high rates of the Fergus sludge is believed to be due, in part at least, to copper toxicity. Treatments that did not receive sludge after the 5th crop produced a slight reduction in plant copper content in the 9th and 10th crops, relative to the treatments receiving sludge. The Guelph sludge produced almost as high copper concentrations in the ryegrass as the Fergus sludge but did not show any sign of toxicity or reduced growth (Tables 102, 103 and 104).

Copper concentrations in all eleven crops of ryegrass receiving the Sarnia and North Toronto sludges (sludges of moderate copper content) are presented in Table 128. There was a tendency for copper content to be lower in the first crop of ryegrass after leaching in treatments receiving sewage sludge. There was no apparent increase in copper concentration from crop to crop with sludge application in spite of the increasing copper concentration in the soil.

Lead concentrations in ryegrass were lower in most cases where sludge was applied than on the check treatment (Tables 129 and 130). The Sarnia sludge, which supplied more lead than other sludges, increased lead concentration in the 10th crop of ryegrass but not in the 11th crop.

Nickel concentrations in the 9th, 10th and 11th crops of ryegrass are presented in Tables 131, 132 and 133. They were relatively high in ryegrass that received the Midland sludge and above average with the Fergus Sludge.

The Midland sludge supplied very large amounts of Ni; the Fergus sludge did not supply appreciably more Ni than the other sludges (Tables 95, 96, and 97) but resulted in higher Ni concentration in the ryegrass.

High nickel concentration, however, did not appear to be toxic to the ryegrass in treatments receiving the Midland sludge. Treatments that did not receive sludge after the fifth crop had lower plant Ni concentration than treatments that continued to receive sludge.

Nickel concentrations in all eleven crops of ryegrass receiving the Midland and North Toronto sludges (the highest and lowest nickel contents of the sludges studied) are presented in Table 134. Leaching of the soil before the 3rd, 5th and 7th, 9th and 11th crops of ryegrass may have lowered the nickel concentration in the following crop of ryegrass to some extent. Nickel concentrations in the ryegrass did not increase from crop to crop.

Zinc concentrations were quite high in ryegrass from treatments receiving the Sarnia sludge and, to a lesser extent, in those receiving Fergus, Guelph and Midland sludges (Tables 135, 136, and 137). The Sarnia and Fergus sludges supplied large amounts of zinc, with Midland and Guelph supplying considerably less but still appreciably more than North Toronto or Aurora sludges (Tables 95, 96 and 97). Omitting application of sludge after the fifth crop reduced the Zn content in the plants compared to treatments continuing to receive sludges. Treatments receiving low rates of the Aurora or North Toronto sludges (both relatively low in zinc) had lower Zn concentrations in the ryegrass than treatments not receiving sludge.

Zinc concentrations in all eleven crops of ryegrass receiving continued applications of the Sarnia and North Toronto sludges (supplying, respectively, the greatest and a relatively small amount of zinc) are presented in Table 138. Leaching of the soil may have resulted in some reduction in zinc concentration in the following crop. There was a tendency for zinc concentration in the ryegrass to increase from the 5th to the 11th crop on treatments receiving Sarnia sludge.

Antimony concentrations in ryegrass were determined on selected treatments and did not appear to have been affected by treatment (Table 139).

Cobalt concentration appeared to have been affected by treatment but differences have not been tested statistically (Table 140).

Mercury concentrations in ryegrass, determined on selected treatments, did not appear to have been affected by treatment (Table 141).

Molybdenum concentration was determined in the ryegrass from selected treatments. Sludge application increased Mo concentration in ryegrass (Table 142). The Guelph sludge added the most molybdenum, followed closely by the Midland sludge. Stopping the application of sludge after the fifth crop appeared to reduce the Mo concentration in the ryegrass.

Selenium concentration was determined in ryegrass from selected treatments (Table 143). The data are too variable to show whether sludge had an effect on Se levels in the ryegrass.

5.4 Summary and Conclusions

Continued application of most sludges resulted in yields of ryegrass which in most cases were as high or higher than yields without sludge when pots were leached after every second crop to remove excess salts. Copper toxicity is believed to have decreased yields with the Fergus sludge. Nickel concentrations were high in ryegrass receiving the Midland sludge, but did not appear to have toxic effects. Omitting the application of sludge after the 5th crop tended to increase the plant cadmium concentration in the 9th and 11th crop of ryegrass, except with the Sarnia sludge. Also sludges low in cadmium decreased cadmium content of the ryegrass, compared to the control. Omitting the application of sludge after the 5th crop increased the nickel concentration in the 9th and 11th crops of ryegrass. Omitting the application of sludge after the 5th crop reduced the Cu, Ni and Zn concentrations in succeeding crops.

The metal concentrations in ryegrass receiving different sludges frequently did not correspond to the amount of metal added. The metals in different sludges, therefore, differ in availability because they are in different chemical form or because their uptake is influenced by other factors which differ from one sludge to another.

With the exception of zinc with the Sarnia sludge there was no indication of an increase in metal concentration in the ryegrass from one crop to the next even with continued applications of sludge.

TABLE 88. CROP MANAGEMENT SCHEDULE, GREENHOUSE EXPERIMENT, 1977.

Operation	9th Crop	10th Crop	11th Crop
Sludge application completed	April 13	June 17	August 12
Leaching completed	April 20		August 20
Potassium Chloride added to all treatments	100 kg K/ha May 3	100 kg K/ha June 24	100 kg K/ha Sept. 7
Ammonium nitrate added to check plots and those receiving only one sludge application or 200 and 800 kg N/ha from sludge for only first five crops*	50 kg N/ha May 3 May 10 May 16 May 24	50 kg N/ha June 24 July 2 July 10 July 18	50 kg N/ha Sept. 7 Sept. 14 Sept. 22 Oct. 1
Ryegrass seeded	May 3	June 24	Sept. 7
Ryegrass harvested	June 3	July 27	Oct. 15

*During the 9th crop treatment receiving 800 kg N/ha from sludge for first five crops received only 100 kg N/ha as ammonium nitrate.

TABLE 89. CHEMICAL ANALYSIS OF SLUDGES USED IN GREENHOUSE FOR 9th CROP OF RYEGRASS (fluid basis).

	Aurora	Midland	Sarnia	Guelph	Fergus	N. Toronto
pH	6.5	6.5	6.9	6.9	6.8	7.0
			mg/ml			
Solids	16	39	49	43	74	68
Total N	0.70	0.50	1.40	1.55	2.50	3.10
Soluble & Exch. NH_4-N	0.11	0.14	0.53	0.46	0.79	1.04
P	0.40	1.80	1.60	2.00	4.55	3.35
K	0.15	0.10	0.30	0.10	0.20	0.20
Ca	1.0	2.8	2.5	4.0	3.3	3.2
Mg	0.10	0.30	0.70	0.40	0.70	0.50
Na	0.38	0.28	0.32	0.33	0.53	0.33
Al	0.64	0.60	0.33	1.19	0.15	1.18
Fe	0.53	2.72	4.13	1.82	7.01	4.86
			μg/ml			
Cu	6	21	36	108	2310	128
Zn	14	135	775	866	1220	169
Mn	3.5	27	379	13	18	71
Cd	0.09	0.39	4.52	4.61	0.42	1.50
Cr	206	87	10	109	1379	54
Ni	1	97	1	4	7	2
Pb	8	23	261	68	24	126
Mo	0.12	0.43	1.08	2.17	0.88	2.53
B	0.35	1.6	1.3	1.6	1.9	1.4
Hg	0.06	0.27	0.31	0.47	0.18	1.44
Se	0.001	0.002	0.002	<0.001	0.001	0.002
Sb	0.005	0.021	0.098	0.022	0.009	0.012
Co	0.05	0.37	.20	0.36	0.18	0.61

TABLE 90. CHEMICAL ANALYSIS OF SLUDGES USED IN GREENHOUSE FOR 10th CROP OF RYEGRASS (fluid basis).

	Aurora	Midland	Sarnia	Guelph	Fergus	N. Toronto
pH	7.4	7.6	7.2	7.4	7.1	7.3
			mg/ml			
Solids	39	43	159	60	122	76
Total N	1.38	0.83	1.60	2.10	3.40	3.10
Soluble & Exch. NH_4	0.12	0.18	0.74	0.46	1.05	1.01
P	1.1	2.2	4.7	2.2	4.8	3.8
K	0.2	0.1	0.7	0.2	0.2	0.3
Ca	2.0	1.0	3.9	5.3	1.5	1.5
Mg	0.2	0.2	1.6	0.4	0.8	0.4
Na	0.32	0.21	0.26	0.27	0.32	0.22
Al	2.34	0.68	0.95	1.08	0.14	1.01
Fe	2.20	4.64	15.7	2.37	11.8	5.93
			µg/ml			
Cu	22	27	91	109	2165	121
Zn	48	183	2178	840	1879	160
Mn	8	26	1113	12	21	55
Cd	0.13	0.37	13.0	5.40	0.70	1.70
Cr	341	114	19	153	1373	52
Ni	1	172	3	5	11	1
Pb	17	29	668	90	26	122
Mo	0.43	0.95	2.70	2.04	1.01	2.74
B	2.5	2.2	3.5	2.1	3.4	1.1
Hg	0.13	0.38	1.62	0.36	0.34	1.79
Se	0.013	0.004	0.005	0.002	0.006	0.010
Sb	0.010	0.042	0.159	0.013	0.027	0.038
Co	0.08	0.65	0.44	0.45	0.25	0.68

TABLE 91. CHEMICAL ANALYSIS OF SLUDGES USED IN GREENHOUSE FOR 11th CROP OF RYEGRASS (fluid basis).

	Aurora	Midland	Sarnia	Guelph	Fergus	N. Toronto
pH	7.1	7.0	7.4	7.4	7.4	7.5
			mg/ml			
Solids	38	81	86	82	61	47
Total N	1.60	1.65	2.55	3.60	2.75	2.50
Soluble & Exch. NH_4	0.32	0.24	0.83	1.03	1.09	1.16
P	1.20	4.20	2.65	3.55	2.65	2.30
K	0.15	0.10	0.45	0.20	0.10	0.20
Ca	1.90	4.86	3.69	5.82	2.44	1.97
Mg	0.20	0.40	0.80	0.50	0.50	0.25
Na	0.27	0.12	0.18	0.24	0.33	0.17
Al	2.28	1.05	0.42	2.46	0.13	0.73
Fe	2.19	7.69	8.60	3.20	5.49	3.57
			µg/ml			
Cu	22	46	50	246	1525	73
Zn	59	296	1333	1184	1113	101
Mn	9	37	559	17	11	25
Cd	0.15	0.65	6.90	10.3	0.31	0.94
Cr	399	247	13	270	839	26
Ni	2	214	2	6	6	1
Pb	18	46	366	176	16	71
Mo	0.35	0.74	0.98	2.61	0.41	1.28
B	2.5	4.1	2.0	2.9	2.3	1.0
Hg	0.15	0.99	0.85	0.62	0.20	1.25
Co	0.31	1.40	0.64	0.99	0.35	0.65

TABLE 92. TOTAL AMOUNTS OF NUTRIENTS AND METALS ADDED IN 9th APPLICATION OF SLUDGE AT 200 kg N/ha TO GREENHOUSE EXPERIMENT.

	Aurora	Midland	Sarnia	Guelph	Fergus	N. Toronto
			kg/ha			
Solids	4,570	15,600	7,000	5,550	5,920	4,390
Total N	200	200	200	200	200	200
Soluble & Exch. NH_4-N	31	56	57	59	62	67
P	114	720	229	258	364	216
K	43	40	43	13	16	13
Ca	285	1,120	357	516	264	206
Mg	29	120	100	52	56	32
Na	109	112	46	43	42	21
Al	183	240	47	154	12	76
Fe	151	1,088	590	235	560	314
Cu	1.7	8.4	5.1	13.9	184.8	8.3
Zn	4.0	54.0	110.7	111.7	97.6	10.9
Mn	1.0	10.8	54.1	1.7	1.4	4.6
Cd	0.03	0.20	0.70	0.60	0.03	0.10
Cr	58.9	34.8	1.4	14.1	110.3	3.5
Ni	0.3	38.8	0.1	0.5	0.6	0.1
Pb	2.3	9.2	37.3	8.8	1.9	8.1
Mo	0.03	0.17	0.15	0.28	0.07	0.16
B	0.10	0.64	0.19	0.21	0.15	0.09
Hg	0.02	0.11	0.04	0.07	0.01	0.09
Se	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Sb	0.001	0.008	0.013	0.002	0.001	0.001
Co	0.014	0.148	0.029	0.046	0.014	0.039

TABLE 93. TOTAL AMOUNTS OF NUTRIENTS AND METALS ADDED IN 10th APPLICATION OF SLUDGE AT 200 kg N/ha TO GREENHOUSE EXPERIMENT.

	Aurora	Midland	Sarnia	Guelph	Fergus	N. Toronto
			kg/ha			
Solids	5,650	10,360	19,880	5,710	7,180	4,900
Total N	200	200	200	200	200	200
Soluble & Exch. NH_4-N	17	43	93	44	62	65
P	159	530	588	210	282	245
K	29	24	88	19	12	19
Ca	290	241	488	504	88	97
Mg	29	48	200	38	47	25
Na	46	51	33	26	19	14
Al	339	164	119	103	8	65
Fe	318	1,118	1,962	226	694	383
Cu	3.2	6.5	11.4	10.4	127.0	7.8
Zn	7	44	272	80	111	10
Mn	1.2	6.3	139.1	1.1	1.2	3.5
Cd	0.02	0.09	1.63	0.51	0.04	0.11
Cr	49.4	27.5	2.4	14.5	80.8	3.4
Ni	0.1	41.5	0.4	0.5	0.7	0.1
Pb	2.5	7.0	83.5	8.6	1.5	7.9
Mo	0.06	0.23	0.34	0.19	0.06	0.18
B	0.36	0.53	0.44	0.20	0.20	0.07
Hg	0.02	0.09	0.20	0.03	0.02	0.12
Se	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Sb	0.001	0.010	0.019	0.001	0.001	0.002
Co	0.012	0.157	0.055	0.043	0.015	0.044

TABLE 94. TOTAL AMOUNTS OF NUTRIENTS AND METALS ADDED IN 11th APPLICATION OF SLUDGE AT 200 kg N/ha TO GREENHOUSE EXPERIMENT.

	Aurora	Midland	Sarnia	Guelph	Fergus	N. Toronto
			kg/ha			
Solids	4750	9820	6750	4560	4440	3760
Total N	200	200	200	200	200	200
Soluble S	40	29	65	57	79	93
Exch. NH_4-N						
P	150	509	208	197	193	184
K	19	12	35	11	7	16
Ca	237	589	289	323	177	157
Mg	25	49	63	28	36	20
Na	34	15	14	13	24	14
Al	285	127	33	137	10	58
Fe	274	932	675	178	399	286
Cu	2.8	5.6	3.9	13.7	111.0	5.8
Zn	7	36	104	66	81	8
Mn	1.1	4.5	43.8	0.9	0.8	2.0
Cd	0.02	0.08	0.54	0.57	0.02	0.08
Cr	50.0	29.9	1.0	15.0	61.0	2.1
Ni	0.3	25.9	0.2	0.3	0.4	0.1
Pb	2.3	5.6	28.7	9.8	1.2	5.7
Mo	0.04	0.09	0.08	0.15	0.03	0.10
B	0.31	0.50	0.16	0.16	0.17	0.08
Hg	0.02	0.12	0.07	0.03	0.02	0.10
Co	0.04	0.17	0.05	0.06	0.03	0.05

TABLE 95. TOTAL AMOUNTS OF NUTRIENTS AND METALS ADDED IN SLUDGE AT 200 kg N/ha PER APPLICATION TO SOIL IN GREENHOUSE EXPERIMENT IN 9 CROPS

	Aurora	Midland	Sarnia	Guelph	Fergus	N. Toronto
			kg/ha			
Solids	59,670	169,100	73,700	50,650	37,520	40,190
Total N	1,800	1,800	1,800	1,800	1,800	1,800
Soluble & Exch. NH_4-N	399	310	559	648	772	610
P	1,204	4,740	1,739	2,208	1,295	1,716
K	262	237	307	148	114	148
Ca	3,055	29,520	3,207	3,246	2,024	1,656
Mg	354	1,650	790	442	446	262
Na	749	372	160	243	335	120
Al	5,823	1,900	423	1,229	119	457
Fe	651	2,628	5,190	1,470	2,200	2,944
Cu	23	71	53	145	467	59
Zn	40	277	957	385	614	124
Mn	12	56	223	14	9	20
Cd	0.24	1.11	7.10	9.60	0.63	1.14
Cr	436	152	12	145	231	24
Ni	7.6	392.8	2.4	4.7	6.3	1.3
Pb	15.3	96.2	293.3	72.8	12.9	78.1
Mo	0.67	2.09	1.80	3.28	0.47	1.28
B	2.80	6.74	1.89	2.11	1.25	0.99
Hg	0.15	1.31	0.43	0.49	0.14	0.79
Se	0.841	0.581	<0.003	1.181	0.027	0.011

TABLE 96. TOTAL AMOUNTS OF NUTRIENTS AND METALS ADDED IN SLUDGE AT 200 kg N/ha PER APPLICATION TO SOIL IN GREENHOUSE EXPERIMENT IN 10 CROPS

	Aurora	Midland	Sarnia	Guelph	Fergus	N.Toronto
			kg/ha			
Solids	65,320	179,500	93,570	56,360	44,700	45,090
Total N	2,000	2,000	2,000	2,000	2,000	2,000
Soluble & Exch. NH_4-N	416	353	652	692	834	675
P	1,363	5,270	2,327	2,418	1,577	1,961
K	291	261	395	167	126	167
Ca	3,345	29,760	3,695	3,750	2,112	1,753
Mg	383	1,698	990	480	493	287
Na	795	423	193	269	354	134
Al	6,162	2,064	542	1,332	127	522
Fe	969	3,746	7,152	1,696	2,894	3,327
Cu	26	78	64	155	594	67
Zn	47	321	1,229	465	725	134
Mn	13	62	362	15	10	24
Cd	0.26	1.20	8.73	10.11	0.67	1.25
Cr	485	180	14	160	312	27
Ni	7.7	434.3	2.8	5.2	7.0	1.4
Pb	17.8	103.2	376.8	81.4	14.4	86.0
Mo	0.73	2.32	2.14	3.47	0.53	1.46
B	3.16	7.27	2.33	2.31	1.45	1.06
Hg	0.17	1.40	0.63	0.52	0.16	0.91
Se	0.842	0.582	<0.004	1.182	0.028	0.012

TABLE 97. TOTAL AMOUNTS OF NUTRIENTS AND METALS ADDED IN SLUDGE AT 200 kg N/ha PER APPLICATION TO SOIL IN GREENHOUSE EXPERIMENT IN 11 CROPS.

	Aurora	Midland	Sarnia	Guelph	Fergus	N. Toronto
			kg/ha			
Solids	70,070	189,300	100,300	60,900	49,100	48,850
Total N	2,200	2,200	2,200	2,200	2,200	2,200
Soluble & Exch. NH_4-N	456	382	717	749	913	768
P	1,513	5,779	2,535	2,615	1,770	2,145
K	310	273	430	178	133	183
Ca	3,582	30,350	3,984	4,073	2,289	1,910
Mg	408	1,747	1,053	508	529	307
Na	829	438	207	282	378	148
Al	6,447	2,191	575	1,469	137	680
Fe	1,243	4,678	7,827	1,874	3,293	3,613
Cu	29	84	68	169	705	73
Zn	54	357	1,333	531	806	142
Mn	14	67	406	16	11	26
Cd	0.28	1.28	9.27	10.68	0.69	1.33
Cr	535	210	15	175	373	29
Ni	8.0	460.2	3.0	5.5	7.4	1.5
Pb	20.1	108.8	405.5	91.2	15.6	91.7
Mo	0.77	2.41	2.22	3.62	0.56	1.56
B	3.47	7.77	2.49	2.47	1.62	1.14
Hg	0.19	1.52	0.70	0.55	0.18	1.01

TABLE 98. CONCENTRATION OF NUTRIENTS AND HEAVY METALS IN LEACHATE FROM SELECTED TREATMENTS BEFORE THE 9th CROP OF RYEGRASS.

Sludge	Rate (kg N/ha)	NH_4-N	NO_3-N	P	K	Ca	Mg	Mn
			mg/l					
None†	200	0.5	85	0.20	3	170	10	0.03
Aurora	1600	4.0	32	0.08	10	121	23	0.08
Midland	200	0.8	17	0.95	4	104	13	0.03
	800	0.3	16	0.45	3	100	29	0.03
	1600	0.8	12	0.39	3	92	35	0.02
	1600*	0.5	4	0.42	3	63	20	0.05
Sarnia	1600	0.5	175	0.13	10	320	91	1.17
Guelph	1600	8.0	153	0.27	11	250	55	0.16
Fergus	1600	5.0	125	0.50	17	265	194	1.73
North Toronto	200	0.5	27	0.67	2	59	8	0.12
	800	8.7	66	0.74	4	129	17	0.81
	1600	6.0	168	1.25	12	275	75	4.00
	1600*	3.8	47	0.55	5	149	25	3.45

† Control, receiving 200 kg N/ha from $(NH_4)_2SO_4$

* Sludge applied only to the 1st crop of ryegrass and not to subsequent crops.

TABLE 98. (CONT'D)

Sludge	Rate	Cu	Zn	Cd	Cr	Ni	Pb	B	Fe
				µg/l					
None	200	27	32	< 1.0	10	5	< 5	300	70
Aurora	1600	38	18	< 1.0	12	8	9	250	190
Midland	200	77	16	< 1.0	8	185	8	570	80
	800	48	38	< 1.0	8	112	6	580	75
	1600	54	19	< 1.0	10	168	8	410	105
	1600*	50	27	< 1.0	7	146	11	340	120
Sarnia	1600	90	3400	25.0	14	29	< 5	590	120
Guelph	1600	232	150	27.0	13	45	29	530	155
Fergus	1600	1107	4500	11.0	16	203	30	400	95
North Toronto	200	46	51	< 1.0	8	8	18	270	130
	800	102	198	4.0	9	19	< 5	300	75
	1600	239	463	10.0	13	43	10	730	165
	1600*	104	196	5.0	9	23	< 5	430	165

TABLE 99. CONCENTRATION OF NUTRIENTS AND HEAVY METALS IN LEACHATE FROM SELECTED TREATMENTS BEFORE THE 11th CROP OF RYEGRASS

Sludge	Rate (kg N/ha)	NH_4-N	NO_3-N	P	K	Ca	Mg	Mn
				Mg/l				
None +	200	1.1	40	1.07	4	86	6	0.06
Aurora	1600	4.3	352	0.08	25	366	80	0.02
	200	0.8	22	0.77	5	114	14	0.02
Midland	800	1.2	29	0.43	6	124	33	0.03
	1600	2.2	123	0.56	15	238	132	0.05
	1600*	3.9	130	0.80	14	288	132	0.07
Sarnia	1600	4.2	296	0.25	11	342	159	1.52
Guelph	1600	6.2	163	0.36	7	352	66	0.09
Fergus	1600	1.2	339	0.51	20	550	58	3.60
	200	3.8	12	1.18	4	96	6	0.02
N. Toronto	800	8.3	111	1.06	8	248	18	0.01
	1600	40.1	356	0.89	13	474	85	0.78
	1600*	14.3	262	0.70	10	404	60	0.79

+ Control, receiving 200 kg N/ha from $(NH_4)_2SO_4$

* Sludge applied only to 1st crop of ryegrass and not to subsequent crops.

TABLE 99. (CONT'D)

Sludge	Rate	Cu	Zn	Cd	Cr	Ni	Pb	Fe
				µg/l				
None	200	28	36	1.0	7	6	< 5	360
Aurora	1600	72	47	1.0	16	28	< 5	350
	200	84	30	1.0	9	231	< 5	160
Midland	800	72	13	1.0	9	325	< 5	290
	1600	85	52	1.0	13	720	< 5	540
	1600*	110	37	1.0	14	860	< 5	110
Sarnia	1600	104	5890	34.0	13	52	< 5	108
Guelph	1600	350	119	21.0	14	54	< 5	218
Fergus	1600	1120	6400	10.0	29	238	< 5	780
	200	72	37	2.0	10	12	< 5	105
North Toronto	800	140	40	2.0	9	27	< 5	140
	1600	205	240	6.0	14	49	< 5	110
	1600*	135	126	5.0	14	37	< 5	118

TABLE 100. TOTAL AMOUNTS OF NUTRIENTS AND HEAVY METALS LEACHED FROM SELECTED TREATMENTS BEFORE THE 9th CROP OF RYEGRASS.

Sludge	Rate kg N/ha	NO_3-N	NH_4-N	K	P	Mg	Fe	Ca	B
					kg/ha				
None†	200	163	1	6	0.39	19	.13	372	0.58
Aurora	1600	43	5	13	0.11	31	.25	162	0.33
Midland	200	32	2	8	1.78	24	.15	195	1.07
	800	34	1	6	0.94	61	.16	209	1.21
	1600	22	2	6	0.72	72	.19	172	0.76
	1600*	10	1	7	1.00	48	.29	150	0.81
Sarnia	1600	401	1	23	0.29	208	.28	733	1.35
Guelph	1600	284	15	20	0.50	102	.29	463	0.98
Fergus	1600	233	9	32	0.94	363	.18	496	0.75
North Toronto	200	54	1	4	1.34	16	.26	118	0.54
	800	127	17	8	1.42	32	.14	248	0.58
	1600	335	12	24	2.49	150	.33	549	1.46
	1600*	91	7	10	1.07	49	.32	290	0.84

† Control, receiving 200 kg N/ha from $(NH_4)_2SO_4$

* Sludge applied only to 1st crop and not to subsequent crops of ryegrass.

TABLE 100. (CONT'D)

Sludge	Rate kg N/ha	Mn	Cu	Zn	Ni	Cd	Cr	Pb
		------------kg/ha------------				------g/ha-------		
None	200	0.06	0.05	0.06	0.01	< 2	19	< 10
Aurora	1600	0.11	0.05	0.03	0.01	< 1	16	12
Midland	200	0.05	0.15	0.03	0.35	< 2	15	15
	800	0.06	0.10	0.08	0.23	< 2	17	13
	1600	0.04	0.10	0.04	0.31	< 2	19	15
	1600*	0.12	0.12	0.07	0.35	< 2	17	26
Sarnia	1600	2.68	0.21	7.79	0.07	57	32	< 11
Guelph	1600	0.29	0.43	0.28	0.08	50	24	53
Fergus	1600	3.23	2.07	8.42	0.38	21	30	56
North Toronto	200	0.24	0.09	0.10	0.02	< 2	16	36
	800	1.56	0.19	0.38	0.04	8	17	< 10
	1600	7.98	0.48	0.92	0.09	20	26	20
	1600*	6.71	0.20	0.38	0.05	10	18	< 10

TABLE 101. TOTAL AMOUNTS OF NUTRIENTS AND HEAVY METALS LEACHED FROM SELECTED TREATMENTS BEFORE THE 11th CROP OF RYEGRASS.

Sludge	Rate kg N/ha	NO_3-N	NH_4-N	K	P	Mg	Fe	Ca
			Kg/ha					
None+	200	67	2	7	1.78	10	0.60	143
Aurora	1600	543	7	39	0.12	123	0.54	564
Midland	200	33	2	8	1.17	21	0.24	173
	800	44	2	9	0.65	50	0.44	188
	1600	174	3	21	0.79	187	0.76	337
	1600*	206	6	22	1.27	209	0.17	456
Sarnia	1600	444	6	17	0.37	238	0.16	513
Guelph	1600	295	11	13	0.65	120	0.40	638
Fergus	1600	642	2	38	0.96	109	1.48	1042
North Toronto	200	19	6	7	1.95	10	0.17	159
	800	150	11	11	1.44	24	0.19	337
	1600	534	60	19	1.33	127	0.17	711
	1600*	472	26	18	1.26	108	0.21	728

+ Control, receiving 200 kg N/ha from $(NH_4)_2SO_4$

* Sludge applied only to 1st crop of ryegrass and not to subsequent crops

TABLE 101. (CONT'D)

Sludge	Rate kg N/ha	Mn	Cu	Zn	Ni	Cd	Cr	Pb
		kg/ha				g/ha		
None	200	0.09	0.05	0.06	.01	2	12	<8
Aurora	1600	0.03	0.11	0.07	.04	2	25	<8
Midland	200	0.03	0.13	0.05	.35	2	14	<8
	800	0.05	0.11	0.02	.50	2	14	<8
	1600	0.07	0.12	0.07	1.02	1	18	<8
	1600*	0.11	0.17	0.06	1.36	2	22	<8
Sarnia	1600	2.28	0.16	8.83	0.08	50	19	<8
Guelph	1600	0.16	0.63	0.22	0.09	38	25	<9
Fergus	1600	6.82	2.12	12.13	0.45	19	55	<9
North Toronto	200	0.03	0.12	0.06	0.02	3	17	<8
	800	0.01	0.19	0.05	0.04	3	12	<7
	1600	1.17	0.31	0.36	0.07	9	21	<7
	1600*	1.43	0.24	0.23	0.07	9	25	<9

TABLE 102. DRY MATTER YIELD OF 9th CROP OF RYEGRASS AFTER ADDITION OF SEWAGE SLUDGE BEFORE EACH OF THE FIRST FIVE CROPS.

	Sludge Not Added Since 5th Crop					Sludge Added Before 9th Crop					
	N rate lb/ac (kg/ha)										Mean
Sludge	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean	
	g D.M./Pot										
None											5.33
Aurora	4.42	2.75	2.38	4.95	3.62	4.22	4.30	5.02	5.63	4.79	4.21
Midland	4.18	2.51	3.06	4.70	3.61	2.76	4.28	5.34	5.32	4.42	4.01
Sarnia	4.27	3.38	3.13	5.30	4.02	2.63	2.26	4.78	4.86	4.13	4.07
Guelph	4.88	4.00	2.52	4.73	4.03	2.60	4.10	5.01	4.27	3.99	4.01
Fergus	3.80	4.72	3.81	5.16	4.37	2.67	4.26	2.53	3.79	3.31	3.84
N. Toronto	5.02	3.11	3.30	4.94	4.09	3.16	4.12	4.00	5.08	4.09	4.09
Mean	4.43	3.41	3.03	4.96	3.96	3.00	4.22	4.44	4.82	4.12	4.04

*Sludge was added before the first crop but not before crops 2, 3, 4 and 5

Significance of "F" test at 0.05 and 0.01 probability

Sludge source - N.S.
Sludge rate - .01
Sludge addition - N.S.
Source x rate - .05
Source x addition - .01
Addition x rate - .01
Source x rate x addition - N.S.

TABLE 103. DRY MATTER YIELD OF 10th CROP OF RYEGRASS AFTER ADDITION OF SEWAGE SLUDGE BEFORE EACH OF THE FIRST FIVE CROPS.

	Sludge Not Added Since 5th Crop					Sludge Added Before 10th Crop					
	N rate lb/ac (kg/ha)										Mean
Sludge	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean	
	g D.M./Pot.										
None											3.86
Aurora	3.78	4.39	2.06	4.47	3.67	4.28	3.97	5.03	3.16	4.11	3.89
Midland	3.84	3.91	3.68	4.11	3.88	3.26	2.89	5.68	5.38	4.30	4.09
Sarnia	4.33	5.04	2.63	5.28	4.32	4.46	6.74	5.83	6.38	5.85	5.08
Guelph	4.84	5.38	1.98	5.23	4.36	3.39	4.73	4.80	4.56	4.37	4.36
Fergus	4.66	4.65	2.26	4.81	4.10	3.25	2.58	0.74	0.77	1.84	2.96
N. Toronto	4.13	4.74	2.02	3.91	3.70	3.85	4.53	5.87	5.29	4.88	4.29
Mean	4.26	4.68	2.44	4.63	4.00	3.75	4.24	4.66	4.25	4.22	4.11

* Sludge was added before the first crop but not before crops 2, 3, 4, and 5

Significance of "F" test at 0.05 and 0.01 probability

Sludge source - .01

Sludge rate - .01

Sludge addition- N.S.

Source x rate - .01

Source x addition - .01

Addition x rate - .01

Source x rate x addition - .01

TABLE 104. DRY MATTER YIELD OF 11th CROP OF RYEGRASS AFTER ADDITION OF SEWAGE SLUDGE BEFORE EACH OF THE FIRST FIVE CROPS.

	Sludge Not Added Since 5th Crop					Sludge Added Before 11th Crop					
	N rate lb/ac (kg/ha)										Mean
Sludge	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean	
	g D.M./Pot.										
None											3.65
Aurora	5.77	6.20	3.05	5.59	5.15	4.39	5.77	6.15	5.58	5.47	5.31
Midland	6.01	5.24	3.27	5.72	5.06	4.46	5.73	6.44	6.24	5.71	5.39
Sarnia	5.04	5.89	3.84	5.85	5.15	5.24	5.86	4.93	6.28	5.58	5.36
Guelph	5.88	6.12	3.56	5.26	5.20	4.93	6.07	6.22	6.12	5.83	5.52
Fergus	5.83	6.24	3.48	5.53	5.27	4.45	4.42	2.76	2.55	3.54	4.41
N. Toronto	5.60	6.28	4.00	5.58	5.36	4.80	5.75	6.53	6.07	5.78	5.57
Mean	5.69	6.00	3.53	5.59	5.20	4.71	5.60	5.50	5.47	5.32	5.26

* Sludge was added before the first crop but not before crops 2, 3, 4, and 5

Significance of "F" test at 0.05 and 0.01 probability

Sludge source - .01

Sludge rate - .01

Sludge addition- N.S.

Source x rate - .01

Source x addition - .01

Addition x rate - .01

Source x rate x addition - .01

TABLE 105. NITROGEN CONCENTRATION IN 9th CROP OF RYEGRASS AFTER ADDITION OF SEWAGE SLUDGE BEFORE EACH OF THE FIRST FIVE CROPS.

	Sludge Not Added Since 5th Crop					Sludge Added Before 9th Crop					
	N rate lb/ac (kg/ha)										Mean
Sludge	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean	
					%N						
None											4.23
Aurora	4.60	2.45	2.80	4.58	3.61	3.18	4.58	5.00	4.90	4.41	4.01
Midland	3.85	3.55	4.00	4.85	4.06	2.55	3.63	4.88	5.08	4.03	4.05
Sarnia	4.18	3.03	2.63	4.33	3.54	1.95	2.63	3.85	2.95	2.84	3.19
Guelph	3.55	2.83	2.30	4.73	3.35	2.40	2.85	3.23	4.10	3.14	3.25
Fergus	4.23	3.08	3.10	4.43	3.71	2.20	3.73	4.20	4.18	3.58	3.64
N. Toronto	4.13	2.53	2.43	4.55	3.41	2.30	3.85	3.95	3.13	3.31	3.36
Mean	4.09	2.91	2.88	4.58	3.61	2.43	3.54	4.18	4.05	3.55	3.58

* Sludge was added before the first crop but not before crops 2, 3, 4 and 5

Significance of "F" test at 0.05 and 0.01 probability

Sludge source - .01

Sludge rate - .01

Sludge addition 0 N.S.

Source x rate - .01

Source x addition -.01

Addition x rate - .01

Source x rate x addition - .01

TABLE 106. NITROGEN CONCENTRATION IN 10th CROP OF RYEGRASS AFTER ADDITION OF SEWAGE SLUDGE BEFORE EACH OF THE FIRST FIVE CROPS.

	Sludge Not Added Since 5th Crop					Sludge Added Before 10th Crop					
	N rate lb/ac (kg/ha)										Mean
Sludge	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean	
					%N						
None											4.48
Aurora	4.25	3.63	1.78	4.10	3.44	1.98	4.98	5.13	5.13	4.30	3.88
Midland	3.83	3.80	1.88	4.03	3.38	1.98	4.50	5.03	4.55	4.01	3.70
Sarnia	3.50	3.93	1.95	4.20	3.39	1.98	4.35	5.23	4.25	3.95	3.67
Guelph	3.43	3.10	1.78	3.95	3.06	2.23	3.70	5.03	5.20	4.04	3.55
Fergus	3.73	3.88	2.05	4.28	3.48	1.80	4.43	4.90	4.53	3.91	3.70
N. Toronto	4.15	4.43	1.83	4.18	3.64	2.50	4.93	5.43	5.20	4.51	4.08
Mean	3.81	3.79	1.88	4.12	3.40	2.08	4.48	5.12	4.80	4.12	3.76

*Sludge was added before the first crop but not before crops 2,3,4 and 5

Significance of "F" test at 0.05 and 0.01 probability

Sludge source - .01

Sludge rate - .01

Sludge addition - .01

Source x rate - N.S.

Source x addition - N.S.

Addition x rate - .01

Source x rate x addition -N.S.

TABLE 107. NITROGEN CONCENTRATION IN 11th CROP OF RYEGRASS AFTER ADDITION OF SEWAGE SLUDGE BEFORE EACH OF THE FIRST FIVE CROPS.

	Sludge Not Added Since 5th Crop					Sludge Added Before 11th Crop					
	N rate lb/ac (kg/ha)										Mean
Sludge	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean	
					% N						
None											
Aurora	4.60	3.90	1.88	4.38	3.69	2.43	5.08	4.85	5.33	4.42	4.77
Midland	4.25	4.80	1.98	4.80	3.96	1.93	4.40	5.23	5.00	4.14	4.05
Sarnia	4.45	4.55	2.05	4.65	3.93	2.18	4.78	5.28	4.83	4.26	4.09
Guelph	4.35	4.15	2.05	4.58	3.78	1.85	3.85	4.48	4.28	3.61	3.70
Fergus	4.73	4.10	1.75	4.05	3.66	1.58	2.95	4.33	3.75	3.15	3.40
N. Toronto	3.88	4.30	1.73	4.18	3.52	1.80	3.38	4.55	4.33	3.51	3.52
Mean	4.38	4.30	1.90	4.44	3.75	1.96	4.08	4.78	4.58	3.85	3.80

* Sludge was added before the first crop but not before crops 2, 3, 4, and 5

Significance of "F" test at 0.05 and 0.01 probability

Sludge source	.01	Source x rate	N.S.
Sludge rate	.01	Source x addition	.01
Sludge addition	N.S.	Addition x rate	.01
		Source x rate x addition	N.S.

TABLE 108. pH VALUES OF SOIL AFTER THE 10TH CROP OF RYEGRASS.

Sludge	Sludge Not Added Since 5th Crop					Sludge Added Before 10th Crop					Mean
	N rate lb/ac (kg/ha)										
	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean	
None											6.4
Aurora	7.4	7.3	7.6	7.2	7.4	7.2	7.5	7.5	7.0	7.3	7.4
Midland	8.0	8.2	8.3	7.4	8.0	8.0	8.0	8.1	7.9	8.0	8.0
Sarnia	7.6	7.2	7.0	7.2	7.3	6.9	6.6	6.4	6.5	6.6	7.0
Guelph	6.9	6.9	6.9	7.3	7.0	7.1	6.8	6.8	6.8	6.9	7.0
Fergus	7.0	7.3	7.3	7.2	7.2	6.5	6.6	6.1	6.1	6.3	6.8
N. Toronto	6.9	7.1	7.0	6.8	7.0	7.1	6.4	6.2	6.4	6.5	6.8
Mean	7.3	7.3	7.4	7.2	7.3	7.1	7.0	6.9	6.8	6.9	7.0

TABLE 109. PHOSPHORUS CONCENTRATION IN 10TH CROP OF RYEGRASS AFTER ADDITION OF SEWAGE SLUDGE BEFORE EACH OF THE FIRST FIVE CROPS.

	Sludge Not Added Since 5th Crop					Sludge Added Before 10th Crop					Mean
	N rate lb/ac (kg/ha)										
Sludge	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean	
	%P										
None											0.42
Aurora	0.47	0.38	0.45	0.40	0.43	0.40	0.47	0.43	0.50	0.45	0.44
Midland	0.49	0.45	0.42	0.61	0.49	0.47	0.49	0.45	0.45	0.46	0.48
Sarnia	0.44	0.46	0.64	0.45	0.50	0.44	0.44	0.50	0.50	0.47	0.48
Guelph	0.48	0.51	0.79	0.47	0.56	0.57	0.56	0.50	0.58	0.55	0.55
Fergus	0.52	0.49	0.58	0.51	0.52	0.57	0.63	0.38	0.39	0.49	0.51
N. Toronto	0.50	0.53	0.76	0.48	0.57	0.55	0.63	0.70	0.63	0.63	0.60
Mean	0.48	0.47	0.61	0.49	0.51	0.50	0.54	0.49	0.51	0.51	0.51

* Sludge was added before the first crop but not before crops 2,3, 4 and 5

Significance of "F" test at 0.05 and 0.01 probability

Sludge source	- .01	Source x rate	- .01
Sludge rate	- .01	Source x addition	- N.S.
Sludge addition	- N.S.	Addition x rate	- .01
		Source x rate x addition	- .01

TABLE 110. POTASSIUM CONCENTRATION IN 9th CROP OF RYEGRASS AFTER ADDITION OF SEWAGE SLUDGE BEFORE EACH OF THE FIRST FIVE CROPS.

	Sludge Not Added Since 5th Crop					Sludge Added Before 9th Crop					
	N rate lb/ac (kg/ha)										Mean
Sludge	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean	
					%K						
None											3.82
Aurora	3.71	3.86	4.05	4.29	3.97	3.34	4.29	5.68	5.21	4.63	4.30
Midland	3.77	4.09	3.99	3.97	3.93	3.35	3.36	3.53	4.00	3.56	3.76
Sarnia	3.50	3.62	3.46	3.86	3.61	3.12	3.18	4.27	3.90	3.62	3.61
Guelph	3.31	3.61	4.11	4.39	3.85	3.18	2.99	3.51	3.10	3.20	3.52
Fergus	3.44	3.89	3.93	4.15	3.85	2.84	3.04	4.02	3.38	3.32	3.59
N. Toronto	3.35	3.53	3.26	3.97	3.53	3.11	2.83	3.09	2.84	2.97	3.25
Mean	3.51	3.76	3.80	4.10	3.79	3.15	3.28	4.01	3.74	3.55	3.67

* Sludge was added before the first crop but not before crops 2,3,4 and 5

Significance of "F" test at 0.05 and 0.01 probability

Sludge source	- .01	Source x rate	- N.S.
Sludge rate	- .01	Source x addition	- .01
Sludge addition	- .01	Addition x rate	- .01
		Source x rate x addition	- .05

TABLE 111. POTASSIUM CONCENTRATION IN 10th CROP OF RYEGRASS AFTER ADDITION OF SEWAGE SLUDGE BEFORE EACH OF THE FIRST FIVE CROPS.

	Sludge Not Added Since 5th Crop					Sludge Added Before 10th Crop					
	N rate lb/ac (kg/ha)										Mean
Sludge	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean	
					%K						
None											2.97
Aurora	2.53	2.68	3.23	2.60	2.76	2.49	3.83	4.80	4.85	3.99	3.37
Midland	2.63	2.83	3.13	2.96	2.89	3.23	3.42	3.60	3.37	3.40	3.14
Sarnia	2.04	2.09	3.03	2.30	2.36	2.48	3.00	4.38	4.10	3.48	2.92
Guelph	1.94	2.03	3.76	2.80	2.63	2.70	2.71	3.40	3.63	3.11	2.87
Fergus	2.17	2.45	3.37	2.92	2.72	2.98	2.91	3.26	2.90	3.01	2.87
N. Toronto	2.30	2.60	3.50	2.41	2.70	2.51	2.54	3.02	2.74	2.70	2.70
Mean	2.27	2.44	3.33	2.66	2.68	2.73	3.06	3.74	3.60	3.28	2.98

*Sludge was added before the first crop but not before crops 2,3,4 and 5

Significance of "F" test at 0.05 and 0.01 probability

Sludge source	- .01	Source x rate	- .05
Sludge rate	- .01	Source x addition	- .01
Sludge addition	- .01	Addition x rate	- .05
		Source x rate x addition	- .01

TABLE 112. CALCIUM CONCENTRATION IN 10th CROP OF RYEGRASS AFTER ADDITION OF SEWAGE SLUDGE BEFORE EACH OF THE FIRST FIVE CROPS.

	Sludge Not Added Since 5th Crop					Sludge Added Before 10th Crop					Mean
	N rate lb/ac (kg/ha)										
Sludge	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean	
	% Ca										
None											1.52
Aurora	1.63	1.24	1.55	1.63	1.51	0.92	1.04	0.98	1.17	1.03	1.27
Midland	1.58	1.18	1.02	1.42	1.30	1.21	1.09	0.89	0.88	1.02	1.16
Sarnia	1.12	1.20	1.07	1.23	1.15	0.99	1.05	1.17	0.99	1.05	1.10
Guelph	1.12	1.04	0.98	1.41	1.14	1.14	1.41	1.24	1.22	1.25	1.19
Fergus	1.25	1.21	1.19	1.41	1.27	1.74	1.68	1.95	2.19	1.89	1.58
N. Toronto	1.38	1.20	1.26	1.54	1.34	1.23	1.45	1.44	1.56	1.42	1.38
Mean	1.34	1.18	1.18	1.44	1.28	1.20	1.28	1.28	1.33	1.27	1.28

*Sludge was added before the first crop but not before crops 2,3,4 and 5

Significance of "F" test at 0.05 and 0.01 probability

Sludge source	- .01	Source x rate	- .01
Sludge rate	- .01	Source x addition	- .01
Sludge addition	- N.S.	Addition x rate	- .01
		Source x rate x addition	- N.S.

TABLE 113. MAGNESIUM CONCENTRATION IN 9th CROP OF RYEGRASS AFTER ADDITION OF SEWAGE SLUDGE BEFORE EACH OF THE FIRST FIVE CROPS.

	Sludge Not Added Since 5th Crop					Sludge Added Before 9th Crop					
	N rate lb/ac (kg/ha)										Mean
Sludge	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean	
					% Mg						
None											0.27
Aurora	0.31	0.28	0.26	0.26	0.28	0.28	0.35	0.40	0.37	0.35	0.31
Midland	0.27	0.32	0.45	0.29	0.33	0.28	0.44	0.63	0.59	0.48	0.41
Sarnia	0.29	0.30	0.35	0.37	0.32	0.26	0.32	0.43	0.34	0.34	0.33
Guelph	0.33	0.30	0.35	0.30	0.32	0.29	0.32	0.38	0.40	0.35	0.33
Fergus	0.36	0.27	0.30	0.27	0.30	0.28	0.32	0.40	0.38	0.34	0.32
N. Toronto	0.29	0.27	0.26	0.27	0.27	0.23	0.32	0.36	0.30	0.30	0.29
Mean	0.31	0.29	0.33	0.29	0.30	0.27	0.34	0.43	0.40	0.36	0.33

*Sludge was added before the first crop but not before crops 2, 3, 4 and 5

Significance of "F" test at 0.05 and 0.01 probability

Sludge source - .01

Sludge rate - .01

Sludge addition - .01

Source x rate - .01

Source x addition - .01

Addition x rate - .01

Source x rate x addition - .05

TABLE 114. MANGANESE CONCENTRATION IN 9th CROP OF RYEGRASS AFTER ADDITION OF SEWAGE SLUDGE BEFORE EACH OF THE FIRST FIVE CROPS.

Sludge	Sludge Not Added Since 5th Crop					Sludge Added Before 9th Crop					Mean
	N rate lb/ac (kg/ha)										
	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean	
	ug Mn/g										
None											78
Aurora	52	60	144	73	82	44	46	170	81	85	83
Midland	56	119	99	132	101	74	95	76	110	89	95
Sarnia	74	27	33	47	45	27	51	53	37	42	43
Guelph	66	39	66	134	76	46	24	42	58	42	59
Fergus	61	38	58	97	63	30	116	189	204	135	99
N. Toronto	67	43	51	66	56	40	45	132	154	93	74
Mean	62	54	75	91	71	43	63	110	107	81	76

*Sludge was added before the first crop but not before crops 2, 3, 4 and 5

Significance of "F" test at 0.05 and 0.01 probability

Sludge source - .01

Sludge rate - .01

Sludge addition - .01

Source x rate - .01

Source x addition - .01

Addition x rate - .01

Source x rate x addition - .01

TABLE 115. MANGANESE CONCENTRATION IN 11th CROP OF RYEGRASS AFTER ADDITION OF SEWAGE SLUDGE BEFORE EACH OF THE FIRST FIVE CROPS.

	Sludge Not added Since 5th Crop					Sludge Added Before 11th Crop					
	N rate lb/ac (kg/ha)										Mean
	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean	
	µg Mn/g										
None											130
Aurora	60	50	82	99	73	36	22	48	39	36	54
Midland	42	67	77	128	78	81	94	31	32	60	68
Sarnia	72	66	31	58	56	29	68	65	60	55	56
Guelph	118	45	45	151	89	51	43	37	48	45	67
Fergus	74	80	20	129	76	37	24	166	103	82	79
N. Toronto	110	49	45	74	69	52	24	49	55	45	57
Mean	79	59	50	106	74	47	46	66	56	54	64

* Sludge was added before the first crop but not before crops 2, 3, 4, and 5

Significance of "F" test at 0.05 and 0.01 probability

Sludge source - .01

Sludge rate - .01

Sludge addition- .01

Source x rate - .01

Source x addition - .01

Addition x rate - .01

Source x rate x addition - .01

TABLE 116. IRON CONCENTRATION IN 9th CROP OF RYEGRASS AFTER ADDITION OF SEWAGE SLUDGE BEFORE EACH OF THE FIRST FIVE CROPS

	Sludge Not Added Since 5th Crop					Sludge Added Before 9th Crop					Mean
	N rate lb/ac (kg/ha)										
Sludge	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean	
					ug Fe/g						
None											83
Aurora	120	55	84	106	91	78	100	99	98	93	92
Midland	79	74	86	98	84	64	68	73	106	78	81
Sarnia	75	64	59	75	68	74	69	65	60	67	68
Guelph	61	80	71	97	77	48	77	103	96	81	79
Fergus	91	70	80	100	85	67	90	88	85	82	84
N. Toronto	71	56	47	69	61	51	79	80	69	70	65
Mean	83	66	71	91	78	63	80	85	85	78	78

* Sludge was added before the first crop but not before crops 2, 3, 4 and 5

Significance of "F" test at 0.05 and 0.01 probability

Sludge source - .01

Sludge rate - .01

Sludge addition - N.S.

Source x rate - .05

Source x addition - N.S.

Addition x rate - .01

Source x rate x addition - N.S.

TABLE 117. IRON CONCENTRATION IN 10th CROP OF RYEGRASS AFTER ADDITION OF SEWAGE SLUDGE BEFORE EACH OF THE FIRST FIVE CROPS

	Sludge Not Added Since 5th Crop					Sludge Added Before 10th Crop					Mean
	N rate lb/ac (kg/ha)										
Sludge	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean	
	ug Fe/g										
None											62
Aurora	108	86	20	102	79	52	78	73	79	70	75
Midland	65	66	53	59	60	48	58	69	69	61	61
Sarnia	78	99	59	92	82	49	87	83	73	73	77
Guelph	63	64	57	73	64	54	74	76	94	74	69
Fergus	74	72	52	105	76	49	88	75	93	76	76
N. Toronto	68	67	47	77	64	67	80	84	94	81	73
Mean	76	75	48	84	71	53	77	77	84	73	72

*Sludge was added before the first crop but not before crops 2,3,4 and 5

Significance of "F" test at 0.05 and 0.01 probability

Sludge source - .01

Sludge rate - .01

Sludge addition - N.S.

Source x rate - .01

Source x addition - .05

Addition x rate - .01

Source x rate x addition - N.S.

TABLE 118. BORON CONCENTRATION IN 9th CROP OF RYEGRASS AFTER ADDITION OF SEWAGE SLUDGE BEFORE EACH OF THE FIRST FIVE CROPS

	Sludge Not Added Since 5th Crop					Sludge Added Before 9th Crop					
	N rate lb/ac (kg/ha)										Mean
Sludge	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean	
	ug B/g										
None											16
Aurora	17	25	29	20	22	21	33	39	39	33	27
Midland	26	50	57	35	42	30	49	84	71	58	50
Sarnia	15	20	28	18	20	17	30	45	32	31	25
Guelph	17	21	29	18	21	19	21	32	31	26	23
Fergus	16	14	18	16	16	16	20	23	24	21	18
N. Toronto	17	22	22	15	19	21	22	24	23	22	21
Mean	18	25	30	20	23	21	29	41	36	32	27

*Sludge was added before the first crop but not before crops 2,3, 4 and 5

Significance of "F" test at 0.05 and 0.01 probability

Sludge source - .01
Sludge rate - .01
Sludge addition - .01

Source x rate - .01
Source x addition - .01
Addition x rate - .01
Source x rate x addition - .01

TABLE 119. BORON CONCENTRATION IN 11th CROP OF RYEGRASS AFTER ADDITION OF SEWAGE SLUDGE BEFORE EACH OF THE FIRST FIVE CROPS.

	Sludge Not Added Since 5th Crop					Sludge Added Before 11th Crop					
	N rate lb/ac (kg/ha)										Mean
Sludge	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean	
	μg B/g										
None											13
Aurora	13	15	19	17	16	21	30	30	36	29	22
Midland	24	34	50	30	34	24	44	62	55	46	40
Sarnia	13	17	22	15	16	17	30	39	39	31	24
Guelph	15	15	20	15	16	16	20	24	25	21	18
Fergus	14	15	14	14	14	17	24	22	20	20	17
N. Toronto	15	17	18	16	16	14	16	18	21	17	17
Mean	16	19	24	17	19	18	27	32	32	27	23

* Sludge was added before the first crop but not before crops 2, 3, 4, and 5.

Significance of "F" test at 0.05 and 0.01 probability

Sludge source - .01
Sludge rate - .01
Sludge addition- .01
Source x rate - .01
Source x addition - .01
Addition x rate - .01
Source x rate x addition - N.S.

TABLE 120. CADMIUM CONCENTRATION IN 9th CROP OF RYEGRASS AFTER ADDITION OF SEWAGE SLUDGE BEFORE EACH OF THE FIRST FIVE CROPS.

	Sludge Not Added Since 5th Crop					Sludge Added Before 9th Crop					
	N rate lb/ac (kg/ha)										Mean
Sludge	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean	
					ug Cd/g						
None											1.92
Aurora	0.50	0.23	0.25	0.77	0.44	0.25	0.31	0.27	0.42	0.31	0.38
Midland	0.35	0.35	0.27	0.38	0.34	0.21	0.27	0.29	0.23	0.25	0.29
Sarnia	1.12	1.11	0.85	0.85	0.98	0.81	0.92	1.85	1.04	1.15	1.07
Guelph	1.66	2.73	5.19	2.39	2.99	1.77	2.19	3.58	1.27	2.20	2.59
Fergus	0.46	0.66	0.77	0.89	0.69	0.35	0.46	0.27	0.54	0.40	0.55
N. Toronto	0.58	0.77	0.54	0.42	0.58	0.42	0.46	0.43	0.48	0.45	0.51
Mean	0.78	0.93	1.31	0.95	1.00	0.63	0.77	1.11	0.66	0.79	0.90

*Sludge was added before the first crop but not before crops 2, 3, 4 and 5

Significance of "F" test at 0.05 and 0.01 probability

Sludge source - .01

Sludge rate - .01

Sludge addition - .01

Source x rate - .01

Source x addition - .01

Addition x rate - N.S.

Source x rate x addition - .01

TABLE 121. CADMIUM CONCENTRATION IN 10th CROP OF RYEGRASS AFTER ADDITION OF SEWAGE SLUDGE BEFORE EACH OF THE FIRST FIVE CROPS.

	Sludge Not Added Since 5th Crop					Sludge Added Before 10th Crop					
	N rate lb/ac (kg/ha)										Mean
	178	712	1424	1424*		178	712	1424	1424*		
Sludge	(200)	(800)	(1600)	(1600)	Mean	(200)	(800)	(1600)	(1600)	Mean	
					ug Cd/g						
None											2.25
Aurora	0.41	0.50	0.18	0.76	0.46	0.29	0.52	0.44	0.58	0.46	0.46
Midland	0.23	0.35	0.23	0.44	0.31	0.41	0.29	0.53	0.50	0.43	0.37
Sarnia	0.96	1.37	1.25	1.55	1.28	0.93	1.46	1.69	1.52	1.40	1.34
Guelph	2.22	3.81	6.60	1.92	3.64	2.33	5.68	4.51	3.44	3.99	3.81
Fergus	0.58	0.55	0.65	1.11	0.72	0.55	0.55	0.44	0.55	0.52	0.62
N. Toronto	1.02	0.53	0.85	1.11	0.88	0.67	0.91	0.85	0.91	0.83	0.85
Mean	0.90	1.18	1.63	1.15	1.21	0.86	1.57	1.41	1.25	1.27	1.24

*Sludge was added before the first crop but not before crops 2,3,4 and 5

Significance of "F" test at 0.05 and 0.01 probability

Sludge source - .01
Sludge rate - .01
Sludge addition - N.S.

Source x rate - .01
Source x addition - N.S.
Addition x rate - .01
Source x rate x addition - .01

TABLE 122. CADMIUM CONCENTRATION IN 11th CROP OF RYEGRASS AFTER ADDITION OF SEWAGE SLUDGE BEFORE EACH OF THE FIRST FIVE CROPS.

	Sludge Not Added Since 5th Crop					Sludge Added Before 11th Crop					
	N rate lb/ac (kg/ha)										Mean
Sludge	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean	
	µg Cd/g										
None											2.00
Aurora	0.71	0.60	0.74	1.12	0.79	0.38	0.48	0.35	0.73	0.48	0.64
Midland	0.52	0.42	0.38	0.69	0.50	0.41	0.42	0.38	0.73	0.48	0.49
Sarnia	1.92	2.20	1.52	1.85	1.86	1.46	2.35	2.92	2.66	2.35	2.11
Guelph	4.50	7.20	4.89	3.08	4.92	2.20	4.41	7.02	4.23	4.46	4.69
Fergus	0.89	0.92	0.96	1.88	1.16	0.66	0.89	0.79	0.68	0.75	0.96
N. Toronto	1.23	0.93	0.81	1.43	1.10	0.68	0.92	1.00	0.83	0.86	0.98
Mean	1.63	2.04	1.55	1.67	1.72	0.96	1.58	2.07	1.64	1.56	1.64

* Sludge was added before the first crop but not before crops 2, 3, 4, and 5.

Significance of "F" test at 0.05 amd 0.01 probability

Sludge source - .01

Sludge rate - .01

Sludge addition- .05

Source x rate - .01

Source x addition - .01

Addition x rate - .01

Source x rate x addition - .01

TABLE 123. CADMIUM CONCENTRATION IN CROPS 1 TO 11 OF RYEGRASS RECEIVING SEWAGE SLUDGES FROM GUELPH AND NORTH TORONTO BEFORE EACH CROP.*

Crop	Control (NH_4NO_3)	Guelph			North Toronto		
		kg N/ha					
	200	200	800	1600	200	800	1600
		µg Cd/g					
First	0.55	1.03	2.15	2.60	0.70	0.70	0.85
Second	0.35	1.10	2.65	5.61	0.45	0.35	0.40
Third**	0.40	0.65	1.90	2.45	1.45	0.55	0.70
Fourth	0.31	0.86	2.18	3.14	0.38	0.64	0.44
Fifth**	0.60	0.95	2.25	3.70	0.50	0.60	0.65
Sixth	1.65	2.05	4.10	5.20	1.00	0.60	0.50
Seventh**	1.45	2.08	4.05	6.18	0.89	0.79	0.75
Eighth	1.05	2.40	4.25	8.05	0.85	1.10	0.90
Ninth**	1.92	1.77	2.19	3.58	0.42	0.46	0.43
Tenth	2.25	2.33	5.68	4.51	0.67	0.91	0.85
Eleventh**	2.00	2.20	4.41	7.02	0.68	0.92	1.00

* The sludge from Guelph supplied the greatest amount of cadmium in the experiment, while the cadmium content of the North Toronto sludge is near the average of the sludges used.

** Plots were leached after sludge application but before seeding.

TABLE 124. CHROMIUM CONCENTRATION IN 9th CROP OF RYEGRASS AFTER ADDITION OF SEWAGE SLUDGE BEFORE EACH OF THE FIRST FIVE CROPS.

	Sludge Not Added Since 5th Crop					Sludge Added Before 7th Crop					Mean
	N rate lb/ac (kg/ha)										
Sludge	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean	
	µg Cr/g										
None											1.21
Aurora	0.81	1.76	2.10	1.43	1.53	1.86	1.65	1.54	1.87	1.73	1.63
Midland	1.76	2.42	2.09	1.65	1.98	1.87	1.87	1.54	1.76	1.76	1.87
Sarnia	1.21	1.98	2.00	2.09	1.82	1.65	2.75	2.42	2.53	2.34	2.08
Guelph	1.65	1.76	2.75	1.65	1.95	1.98	1.54	2.97	1.76	2.06	2.01
Fergus	1.98	2.09	1.87	2.62	2.14	1.76	2.86	2.53	2.42	2.39	2.27
N. Toronto	1.21	1.54	1.76	1.21	1.43	1.76	1.87	2.42	2.20	2.07	1.75
Mean	1.44	1.93	2.10	1.77	1.81	1.82	2.09	2.24	2.09	2.06	1.93

*Sludge was added before the first crop but not before crops 2,3,4 and 5

Significance of "F" test at 0.05 and 0.01 probability

Sludge source	-.01	Source x rate	- .05
Sludge rate	- .01	Source x addition	- .05
Sludge addition	- .01	Addition x rate	- N.S.
		Source x rate x addition	- N.S.

TABLE 125. COPPER CONCENTRATION IN 9th CROP OF RYEGRASS AFTER ADDITION OF SEWAGE SLUDGE BEFORE EACH OF THE FIRST FIVE CROPS.

	Sludge Not Added Since 5th Crop					Sludge Added Before 9th Crop					Mean
	N rate lb/ac (kg/ha)										
Sludge	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean	
					μg Cu/g						
None											13
Aurora	14	11	14	15	13	12	16	19	18	16	15
Midland	15	19	19	18	18	13	18	25	24	20	19
Sarnia	18	17	15	23	18	10	18	26	21	19	18
Guelph	20	20	18	24	20	14	21	26	25	21	21
Fergus	22	27	30	26	26	18	34	34	37	31	28
N. Toronto	14	13	16	16	15	12	21	23	19	18	16
Mean	17	18	18	20	18	13	21	25	24	21	20

*Sludge was added before the first crop but not before crops 2, 3, 4 and 5

Significance of "F" test at 0.05 and 0.01 probability

Sludge source - .01
Sludge rate - .01
Sludge addition - .01
Source x rate - N.S.
Source x addition - N.S.
Addition x rate - .01
Source x rate x addition - N.S.

TABLE 126. COPPER CONCENTRATION IN 10th CROP OF RYEGRASS AFTER ADDITION OF SEWAGE SLUDGE BEFORE EACH OF THE FIRST FIVE CROPS.

	Sludge Not Added Since 5th Crop					Sludge Added Before 10th Crop					Mean
	N rate lb/ac (kg/ha)										
Sludge	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean	
	ug Cu/g										
None											9
Aurora	12	13	8	12	11	8	17	17	18	15	13
Midland	12	18	12	15	14	9	20	25	23	19	17
Sarnia	14	24	11	20	17	9	26	27	23	21	19
Guelph	16	20	16	18	17	11	22	29	24	21	19
Fergus	18	26	17	23	21	12	34	29	23	24	23
N. Toronto	14	22	9	14	15	12	20	23	21	19	17
Mean	14	20	12	17	16	10	23	25	22	20	18

*Sludge was added before the first crop but not before crops 2,3,4 and 5

Significance of "F" test at 0.05 and 0.01 probability

Sludge source	.01	Source x rate	.01
Sludge rate	.01	Source x addition	N.S.
Sludge addition	.01	Addition x rate	.01
		Source x rate x addition	N.S.

TABLE 127. COPPER CONCENTRATION IN 11th CROP OF RYEGRASS AFTER ADDITION OF SEWAGE SLUDGE BEFORE EACH OF THE FIRST FIVE CROPS.

	Sludge Not Added Since 5th Crop					Sludge Added Before 11th Crop					
	N rate lb/ac (kg/ha)										Mean
Sludge	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean	
None											8
Aurora	13	14	10	12	12	15	20	20	19	18	15
Midland	14	19	9	18	15	11	22	23	23	20	17
Sarnia	13	20	10	19	15	10	26	30	26	23	19
Guelph	17	22	12	18	17	11	21	30	22	21	19
Fergus	19	28	15	23	21	14	23	23	20	20	20
N. Toronto	15	21	10	15	15	9	16	22	20	17	16
Mean	15	20	11	17	16	11	21	24	21	20	18

* Sludge was added before the first crop but not before crops 2, 3, 4, and 5

Significance of "F" test at 0.05 and 0.01 probability

Sludge source - .01

Sludge rate - .01

Sludge addition- .01

Source x rate - .05

Source x addition - .01

Addition x rate - .01

Source x rate x addition - N.S.

TABLE 128. COPPER CONCENTRATION IN CROPS 1 TO 11 OF RYEGRASS RECEIVING SEWAGE SLUDGES FROM SARNIA AND NORTH TORONTO BEFORE EACH CROP.

Crop	Control (NH_4NO_3)	Sarnia			North Toronto		
	kg N/ha						
	200	200	800	1600	200	800	1600
	µg Cu/g						
First	11	15	19	20	13	17	17
Second	17	25	32	31	26	28	27
Third*	10	6	10	11	8	12	13
Fourth	14	12	18	25	11	17	19
Fifth*	14	14	17	20	10	16	18
Sixth	22	14	26	33	21	25	24
Seventh*	13	10	14	34	12	19	19
Eighth	10	18	27	35	21	27	26
Ninth*	13	10	18	26	12	21	23
Tenth	9	9	26	27	12	20	23
Eleventh*	8	10	26	30	9	16	22

* Plots were leached after sludge application but before seeding.

TABLE 129. LEAD CONCENTRATION IN 10th CROP OF RYEGRASS AFTER ADDITION OF SEWAGE SLUDGE BEFORE EACH OF THE FIRST FIVE CROPS.

	Sludge Not Added Since 5th Crop					Sludge Added Before 10th Crop					
	N rate lb/ac (kg/ha)										Mean
Sludge	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean	
					ug Pb/g						
None											1.85
Aurora	1.62	1.18	1.33	1.47	1.40	1.76	1.33	1.33	2.06	1.62	1.51
Midland	0.80	1.41	1.33	1.77	1.32	1.18	1.91	1.76	2.35	1.80	1.56
Sarnia	1.03	1.47	1.18	1.62	1.32	1.47	2.94	3.24	2.21	2.47	1.89
Guelph	1.91	1.62	2.06	1.62	1.80	1.33	1.76	1.62	1.76	1.62	1.71
Fergus	1.32	1.62	1.62	1.17	1.43	1.47	1.62	1.62	1.47	1.54	1.49
N. Toronto	1.76	1.76	1.47	2.06	1.76	1.62	1.76	1.77	1.62	1.69	1.72
Mean	1.41	1.51	1.49	1.62	1.51	1.47	1.89	1.89	1.91	1.79	1.65

* Sludge was added before the first crop but not before crops 2, 3, 4 and 5

Significance of "F" test at 0.05 and 0.01 probability

Sludge source	- .01	Source x rate	- .01
Sludge rate	- .01	Source x addition	- .01
Sluge addition	- .01	Addition x rate	- N.S.
		Source x rate x addition	- .05

TABLE 130. LEAD CONCENTRATION IN 11th CROP OF RYEGRASS AFTER ADDITION OF SEWAGE SLUDGE BEFORE EACH OF THE FIRST FIVE CROPS.

	Sludge Not Added Since 5th Crop					Sludge Added Before 11th Crop					Mean
	N rate lb/ac (kg/ha)										
	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean	
	µg Pb/g										
None											1.52
Aurora	0.63	0.70	0.88	0.97	0.79	0.69	0.77	0.65	0.54	0.66	0.73
Midland	0.86	1.15	1.17	1.26	1.11	0.70	0.72	0.77	0.75	0.73	0.92
Sarnia	1.17	1.44	1.28	1.11	1.25	0.82	1.02	1.02	1.10	0.99	1.12
Guelph	1.20	1.23	1.30	1.22	1.23	0.81	0.42	1.24	0.70	0.79	1.01
Fergus	1.58	1.22	1.33	1.20	1.33	0.67	0.72	0.75	0.73	0.71	1.02
N. Toronto	1.22	1.22	1.19	1.41	1.26	0.85	0.74	0.79	1.05	0.86	1.06
Mean	1.11	1.16	1.19	1.19	1.16	0.75	0.73	0.87	0.81	0.79	0.98

*Sludge was added before the first crop but not before crops 2, 3, 4 and 5.

Significance of "F" test at 0.05 and 0.01 probability

Sludge source - .01
Sludge rate - N.S.
Sludge addition - .01
Source x rate - .05
Source x addition - .01
Addition x rate - N.S.
Source x rate x addition - .05

TABLE 131. NICKEL CONCENTRATION IN 9th CROP OF RYEGRASS AFTER ADDITION OF SEWAGE SLUDGE BEFORE EACH OF THE FIRST FIVE CROPS.

	Sludge Not Added Since 5th Crop					Sludge Added Before 9th Crop					
	N rate lb/ac (kg/ha)										Mean
Sludge	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean	
	ug Ni/g										
None											0.8
Aurora	0.3	0.8	0.7	0.6	0.6	0.7	0.8	1.0	1.0	0.9	0.7
Midland	5.7	15.0	21.2	14.7	14.1	7.5	20.2	33.8	24.2	21.4	17.8
Sarnia	0.7	0.7	0.9	1.0	0.8	0.7	1.0	1.8	1.1	1.1	1.0
Guelph	0.6	1.3	1.1	0.8	0.9	0.7	0.9	1.8	1.3	1.2	1.1
Fergus	0.6	0.8	0.9	0.8	0.8	0.9	2.0	5.0	3.8	2.9	1.9
N. Toronto	0.7	0.7	0.5	0.8	0.7	0.7	0.8	1.1	1.0	0.9	0.8
Mean	1.4	3.2	4.2	3.1	3.0	1.8	4.3	7.4	5.4	4.7	3.9

*Sludge was added before the first crop but not before crops 2, 3, 4 and 5

Significance of "F" test at 0.05 and 0.01 probability

Sludge source - .01

Sludge rate - .01

Sludge additon - .01

Source x rate - .01

Source x addition - .01

Addition x rate - .05

Source x rate x addition - N.S.

TABLE 132. NICKEL CONCENTRATION IN 10th CROP OF RYEGRASS AFTER ADDITION OF SEWAGE SLUDGE BEFORE EACH OF THE FIRST FIVE CROPS.

	Sludge Not Added Since 5th Crop					Sludge Added Before 10th Crop					
	N rate lb/ac (kg/ha)										Mean
Sludge	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean	
					ug Ni/g						
None											1.3
Aurora	0.6	0.9	0.6	0.7	0.7	1.0	1.3	1.2	1.2	1.2	0.9
Midland	7.2	19.7	18.7	19.7	16.3	10.8	29.8	43.9	32.7	29.1	22.7
Sarnia	0.6	0.7	1.1	0.6	0.7	1.0	1.7	2.0	2.0	1.7	1.2
Guelph	0.7	0.9	1.0	0.7	0.8	0.9	1.5	2.4	2.0	1.7	1.3
Fergus	0.8	1.0	0.9	0.8	0.9	1.6	3.2	5.5	3.7	3.5	2.2
N. Toronto	0.7	0.7	1.0	0.8	0.8	1.0	0.9	1.3	1.2	1.1	0.9
Mean	1.7	3.9	3.9	3.9	3.4	2.7	6.4	9.2	7.1	6.4	4.9

*Sludge was added before the first crop but not before crops 2,3,4, and 5

Significance of "F" test at 0.05 and 0.01 probability

Sludge source	- .01	Source x rate	- .01
Sludge rate	- .01	Source x addition	- .01
Sludge addition	- .01	Addition x rate	- .01
		Source x rate x addition	- .01

TABLE 133. NICKEL CONCENTRATION IN 11th CROP OF RYEGRASS AFTER ADDITION OF SEWAGE SLUDGE BEFORE EACH OF THE FIRST FIVE CROPS.

	Sludge Not Added Since 5th Crop					Sludge Added Before 11th Crop					
	N rate lb/ac (kg/ha)										Mean
Sludge	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean	
					µg Ni/g						
None											0.85
Aurora	1.0	0.8	0.8	0.8	0.8	0.9	1.3	1.2	1.0	1.1	1.0
Midland	7.5	20.5	21.4	26.1	18.9	10.4	27.3	39.7	33.5	27.8	23.3
Sarnia	1.2	0.9	0.9	0.8	1.0	1.2	1.8	2.0	2.0	1.8	1.4
Guelph	1.0	1.2	0.8	0.8	1.0	0.8	1.8	2.1	1.8	1.6	1.3
Fergus	0.8	0.7	0.9	0.8	0.8	1.2	2.5	4.8	3.6	3.0	1.9
N. Toronto	1.0	0.9	0.8	0.8	0.9	1.0	1.3	1.6	1.6	1.4	1.1
Mean	2.1	4.2	4.3	5.0	3.9	2.6	6.0	8.6	7.2	6.1	5.0

* Sludge was added before the first crop but not before crops 2, 3, 4, and 5.

Significance of "F" test at 0.05 and 0.01 probability

Sludge source - .01
Sludge rate - .01
Sludge addition- .01

Source x rate - .01
Source x addition - .01
Addition x rate - .01
Source x rate x addition - .01

TABLE 134. NICKEL CONCENTRATION IN CROPS 1 TO 11 OF RYEGRASS RECEIVING SEWAGE SLUDGES FROM MIDLAND AND NORTH TORONTO BEFORE EACH CROP.

Crop	Control (NH_4NO_3)	Midland			North Toronto		
		kg N/ha					
	200	200	800	1600	200	800	1600
		µg Ni/g					
First	2.0	8.5	32.0	32.0	3.5	4.0	4.5
Second	1.8	14.6	36.3	40.8	1.0	1.1	1.9
Third*	0.5	14.5	22.5	34.5	1.0	0.5	2.0
Fourth	2.0	18.8	36.8	51.3	3.9	3.4	4.4
Fifth*	3.0	8.1	23.0	29.0	1.0	1.5	3.5
Sixth	1.2	12.0	35.0	36.0	0.8	2.2	2.4
Seventh*	1.3	11.5	32.5	40.0	0.5	0.8	1.2
Eighth	0.9	12.9	28.0	42.0	1.5	1.5	1.6
Ninth*	0.8	7.5	20.2	33.8	0.7	0.8	1.1
Tenth	1.3	10.8	29.8	43.9	1.0	0.9	1.3
Eleventh*	0.9	10.4	27.3	39.7	1.0	1.3	1.6

The sludge from Midland supplied the greatest amount of nickel in the experiment, while the North Toronto sludge may be considered to be average among the sludges used in its nickel content.

* Indicates pots were leached after sludge application but before seeding.

TABLE 135. ZINC CONCENTRATION IN 9th CROP OF RYEGRASS AFTER ADDITION OF SEWAGE SLUDGE BEFORE EACH OF THE FIRST FIVE CROPS.

	Sludge Not Added Since 5th Crop					Sludge Added Before 9th Crop					Mean
	N rate lb/ac (kg/ha)										
Sludge	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean	
	µg Zn/g										
None											36
Aurora	25	29	45	27	31	27	52	84	73	59	45
Midland	33	61	78	44	54	43	78	136	113	93	73
Sarnia	88	128	191	140	137	102	275	459	289	281	209
Guelph	60	79	116	71	81	61	96	143	117	104	93
Fergus	77	106	153	92	107	99	170	224	196	172	139
N. Toronto	38	48	54	45	46	42	71	93	64	68	57
Mean	54	75	106	70	76	62	124	190	142	129	103

*Sludge was added before the first crop but not before crops 2,3 , 4 and 5

Significance of "F" test at 0.05 and 0.01 probability

Sludge source - .01

Sludge rate - .01

Sludge addition - .01

Source x rate - .01

Source x addition - .01

Addition x rate - .01

Source x rate x addition - .01

TABLE 136. ZINC CONCENTRATION IN 10th CROP OF RYEGRASS AFTER ADDITION OF SEWAGE SLUDGE BEFORE EACH OF THE FIRST FIVE CROPS.

	Sludge Not Added Since 5th Crop					Sludge Added Before 10th Crop					
	N rate lb/ac (kg/ha)										Mean
Sludge	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean	
	µg Zn/g										
None											32
Aurora	15	29	33	15	23	23	62	74	71	57	40
Midland	24	50	41	32	37	37	94	137	107	94	65
Sarnia	59	152	163	104	119	117	420	591	478	402	260
Guelph	45	71	116	43	69	54	150	187	132	131	100
Fergus	57	96	102	65	80	109	215	245	270	209	145
N. Toronto	35	46	49	36	41	39	84	119	87	82	62
Mean	39	74	84	49	61	63	171	225	191	162	112

*Sludge was added before the first crop but not before crops 2,3,4 and 5

Significance of "F" test at 0.05 and 0.01 probability

Sludge source - .01

Sludge rate - .01

Sludge addition - .01

Source x rate - .01

Source x addition - .01

Addition x rate - .01

Source x rate x addition - .01

TABLE 137. ZINC CONCENTRATION IN 11th CROP OF RYEGRASS AFTER ADDITION OF SEWAGE SLUDGE BEFORE EACH OF THE FIRST FIVE CROPS.

	Sludge Not Added Since 5th Crop					Sludge Added Before 11th Crop					
	N rate lb/ac (kg/ha)										Mean
	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean	178 (200)	712 (800)	1424 (1600)	1424* (1600)	Mean	
	µg Zn/g										
None											56
Aurora	24	39	36	24	30	22	61	56	67	51	41
Midland	29	64	49	42	46	42	102	144	128	104	75
Sarnia	80	163	153	111	126	136	553	784	706	545	336
Guelph	71	90	95	56	78	52	122	215	147	134	106
Fergus	81	114	107	87	97	127	249	204	158	184	141
N. Toronto	42	108	43	47	60	38	77	117	86	79	69
Mean	54	96	80	61	73	69	194	253	215	183	128

* Sludge was added before the first crop but not before crops 2, 3, 4, and 5.

Significance of "F" test at 0.05 and 0.01 probability

Sludge source - .01
Sludge rate - .01
Sludge addition- .01

Source x rate - .01
Source x addition - .01
Addition x rate - .01
Source x rate x addition - .01

TABLE 138. ZINC CONCENTRATION IN CROPS 1 TO 11 OF RYEGRASS RECEIVING SEWAGE SLUDGES FROM SARNIA AND NORTH TORONTO BEFORE EACH CROP.

Crop	Control (NH_4NO_3)	Sarnia			North Toronto		
	kg N/ha						
	200	200	800	1600	200	800	1600
	µg Zn/g						
First	43	59	167	241	53	64	72
Second	38	105	218	211	37	66	81
Third*	31	92	146	245	41	70	102
Fourth	32	64	156	103	29	68	112
Fifth*	33	44	122	165	30	58	92
Sixth	51	104	292	490	61	117	130
Seventh*	36	99	209	426	47	75	86
Eighth	33	177	309	530	60	121	130
Ninth*	36	102	275	459	42	71	93
Tenth	32	117	420	591	39	84	119
Eleventh*	55	136	553	784	38	77	117

The sludge from Sarnia supplied the greatest amount of zinc in the experiment, while the North Toronto sludge may be considered to be average among the sludges used in its zinc content.

* Indicates pots were leached after sludge application but before seeding.

TABLE 139. ANTIMONY CONCENTRATION IN RYEGRASS FROM SELECTED TREATMENTS OF GREENHOUSE EXPERIMENT.

Sludge Treatment	Sludge Not Added After 5th Crop	Sludge Added Before Each Crop
	µg Sb/g	
9th Crop		
Aurora 1600 kg N/ha	*	<0.01
Midland 1600 kg N/ha	<0.01	0.01
Guelph 800 kg N/ha	0.02	*
Guelph 1600 kg N/ha	0.01	*
N. Toronto 1600 kg N/ha	0.01	<0.01
Control	---------- <0.01 ------------	
10th Crop		
Aurora 1600 kg N/ha	*	<0.01[+]
Midland 1600 kg N/ha	*	0.01
Guelph 1600 kg N/ha	0.02[+]	0.01
N. Toronto 1600 kg N/ha	0.02	0.02
Control	---------- <0.01 ------------	

[+] Indicates result of one of two replicates, or of samples composited from two replicates if plant material was insufficient.

*No analysis becuase of insufficient material.

TABLE 140. COBALT CONCENTRATION IN RYEGRASS FROM SELECTED TREATMENTS OF GREENHOUSE EXPERIMENT.

Sludge Treatment	Sludge Not Added After 5th Crop	Sludge Added Before Each Crop
	μg Co/g	
9th Crop		
Midland 800 kg N/ha	0.36	0.39
Midland 1600 kg N/ha	*	0.51
N. Toronto 800 kg N/ha	0.44	0.61
N. Toronto 1600 kg N/ha	0.41	0.60
Control	0.44	
10th Crop		
Midland 800 kg N/ha	0.56	0.65
Midland 1600 kg N/ha	0.55[+]	0.71
N. Toronto 800 kg N/ha	0.61	0.63
N. Toronto 1600 kg N/ha	*	0.81
Control	*	

[+] Result of one replicate or of samples composited from two replicates because of insufficient plant material.

*No analysis because of insufficient material.

TABLE 141. MERCURY CONCENTRATION IN RYEGRASS FROM SELECTED TREATMENTS OF GREENHOUSE EXPERIMENT.

Sludge Treatment	Sludge Not Added After 5th Crop		Sludge Added Before Each Crop
		μg Hg/g	
9th Crop			
Midland 800 kg N/ha	0.07		0.07
Midland 1600 kg N/ha	0.07		0.08
N. Toronto 800 kg N/ha	0.08		0.08
N. Toronto 1600 kg N/ha	0.08		0.08
Control	-----------	0.07	-----------
10th Crop			
Midland 800 kg N/ha	0.08		0.08
Midland 1600 kg N/ha	0.08		0.08
N. Toronto 800 kg N/ha	0.08		0.08
N. Toronto 1600 kg N/ha	0.08		0.08
Control	-----------	0.07	-----------

TABLE 142. MOLYBDENUM CONCENTRATION IN RYEGRASS FROM SELECTED TREATMENTS OF GREENHOUSE EXPERIMENT.

Sludge Treatment	Sludge Not Added After 5th Crop		Sludge Added Before Each Crop
		µg Mo/g	
9th Crop			
Midland, 800 kg N/ha	1.86		2.23
Midland, 1600 kg N/ha	1.87		2.19
Guelph, 800 kg N/ha	2.08		2.66
Guelph, 1600 kg N/ha	2.34		3.28
Control	----------	0.63	----------
10th Crop			
Midland, 800 kg N/ha	1.80		2.29
Midland, 1600 kg N/ha	1.80		1.83
Guelph, 800 kg N/ha	2.06		2.13
Guelph, 1600 kg N/ha	2.16		1.70
Control	----------	0.85	----------

TABLE 143. SELENIUM CONCENTRATION IN RYEGRASS FROM SELECTED TREATMENTS OF GREENHOUSE EXPERIMENT.

Sludge Treatment	Sludge Not Added After 5th Crop	Sludge Added Before Each Crop
	µg Se/g	
9th Crop		
Aurora 1600 kg N/ha	0.01	0.01[+]
Midland 1600 kg N/ha	0.02	0.01
Guelph 1600 kg N/ha	0.02	<0.01[+]
Control	0.02	
10th Crop		
Aurora 1600 kg N/ha	-	0.01[+]
Midland 1600 kg N/ha	-	0.02
Guelph 1600 kg N/ha	<0.01	<0.01[+]
Control	0.01[+]	

[+] Indicates result of one of two replicates, or of samples composited from two replicates if plant material was insufficient.

- Indicates no analysis becuase of insufficient material.

APPENDIX

SOIL CHARACTERIZATION

by

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APPENDIX

SOIL CHARACTERIZATION

OBJECTIVES

1) To determine the effect of sewage sludge on soil structure.
2) To determine to what extent sludge has moved and in what form it exists in the soil at lower depth.

METHODS AND MATERIALS

One soil profile was taken from one replicate of the 1600 kg/ha N treatment of each of the three sludges (iron, alum and lime) at each of the three corn plots (Elora, Cambridge and Milton). The locations of each of these profiles are shown for each research plot: 1) Elora (Figure A-1); 2) Cambridge (Figure A-5); and 3) Milton (Figure A-9). On each of these figures the locations of the two check profiles sampled in 1973 are also shown.

The profiles were described according to "The System of Soil Classification for Canada" (Canada Department of Agriculture, 1974). Particle size analyses were done by sieving and the pipette method (Kilmer and Alexander, 1949) following the destruction of organic matter with H_2O_2 and dispersion by calgon (Tyner, 1949). The pH determinations were done in 1:1 soil to water suspensions and in 0.01 $CaCl_2$ (Jackson, 1958). Determination of Na-dithionite and NH_4-oxalate-extractable Fe Al and Mn were made by atomic absorption (Raad et al., 1969). $CaCO_3$ equivalent was determined by the HCl method (Walker, 1965).

RESULTS AND DISCUSSION

Variability of Soils

The need to understand the nature of soil variability in fields receiving sewage sludge has been discussed by Protz (1974). The horizon variability of the soils on the research plots has been reported (Departments of Land Resource Science and Microbiology, University of Guelph, 1975).

Detailed descriptions of each soil profile sampled from the plots receiving the 1600 kg/ha N treatments are included in Tables A-1 to

A-9. Descriptions of the two soil profiles from check areas were published previously (Departments of Land Resource Science and Microbiology, University of Guelph, 1975).

Variability within the iron-sludge replicates from the Milton plots is emphasized by: 1) the description of the sub-profile samples on the opposite side of the pit (Table A-7); 2) comparison of the clay content at comparable depths of these two profiles (Table A-16); and 3) the pH values of these two profiles (Table A-25).

The horizon variation within each of the plots is most easily comprehended by viewing Figures A-2 to A-4 for the Elora plots, Figures A-6 to A-8 for the Cambridge plots, and Figures A-10 to A-12 for the Milton plots.

Particle size distributions (Tables A-10 to A-18) indicate the variation and similarity of the soils. The iron (Table A-10) and alum (Table A-11) sludge soil profiles had higher clay contents than the lime sludge (Table A-12) soil profile.

The soil profile from the Cambridge plots had similar particle size distributions except that the profile from the iron sludge (Table A-13) had a Bt horizon closer to the surface than the alum sludge (Table A-14) or lime sludge (Table A-15) profiles.

Soil Structure

All three of the lime sludge treated soil profiles had increased earthworm activity (Tables A-1 to A-9). With the addition of lime sludge the surface pH, $CaCO_3$ content and organic matter contents were increased, resulting in a better medium for earthworm propagation. This increased earthworm activity will result in:

1) Incorporation of the sludge into the lower horizons of the soil making a larger volume of soil material available for absorption of sludge metals, and leaving less metals in the major rooting layers.
2) An increase in the porosity of soil thus making the movement of sludge constituents into the groundwater easier during high rainfall.

3) Reconstitution of the sludge materials during ingestion by earthworms, leaving new unknown organo-metallic compounds on pore walls.

Movement of Sludge into Soils

On the Elora grass plot experiments, after two years of sludge application, Ca from the lime sludge had moved down to depths of 12 inches, Fe from iron sludge had moved down to the depth of two inches, and Al from alum sludge had moved down only to a depth of one inch (Departments of Land Resource Science and Microbiology, 1976).

In the corn plots the surface-applied sludge was incorporated into the plow layer during seedbed preparation. During plowing the sludge particles are brought into contact with a larger surface area of soils thus increasing the chances of absorption. Thus movement can only be concluded if the added sludge constituents are found below the plough layer.

Evidence of movement was found in earthworm casts, and $CaCO_3$ and extractable Fe and Al distribution with depth.

Changes in $CaCO_3$ Equivalent

The Luvisolic and Brunisolic soils of southern Ontario often have a slight buildup of $CaCO_3$ in the Ap* layers as compared to the Ae horizons. It is accepted that this buildup is due to the Ca from decomposing plant material. The check profiles from the Elora, Cambridge and Milton corn plots had slight increases of $CaCO_3$ in the surface horizons (Departments of Land Resource Sciences and Microbiology, 1975).

The soil profiles receiving lime sludge had marked increases in $CaCO_3$ content in the surface horizons, Elora (Table A-21), Cambridge (Table A-24) and Milton (Table A-27).

There was a slight buildup of $CaCO_3$ in the iron sludge treated soil profile at Elora (Table A-19) and at Cambridge (Table A-22), but not at Milton (Table A-25).

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* The significance of this and other symbols is given in the tables.

A similar buildup of $CaCO_3$ was found in the alum sludge-treated soil profiles at Elora (Table A-20) and Cambridge (Table A-23), but to a lesser extent at Milton (Table A-26).

Movement of NH_4-Oxalate-Extractable Fe, Al, and Mn

NH_4-oxalate-extractable Fe

NH_4-oxalate-extractable cations are considered to be bound to organic matter. Thus an increase of NH_4-oxalate Fe with depth in soil profiles treated with iron, alum or lime sludges over Fe contents in check profiles is interpreted as movement of sludge Fe.

The higher contents of NH_4-oxalate Fe in the 0-6 inch layer (Ap horizon) of the sludge-treated soils are due to the amounts of applied organic-bound Fe in the Elora soil profiles (Figure A-2). The higher contents of the NH_4-oxalate-extractable Fe in the 6-12 inch layer is attributed to the movement of sludge-applied Fe (Figure A-2). In the soil profile receiving lime sludge, Fe may have moved to the 15 inch depth (Figure A-2). Below 15 inches the NH_4-oxalate-extractable Fe contents were close to contents measured in the two check profiles (Figure A-2).

The increase of NH_4-oxalate-extractable Fe in the 0-6 inch layer of the Cambridge soil profiles that received sludge is due to the Fe in the sludge (Figure A-6). The higher NH_4-oxalate-extractable Fe contents in the 6-18 inch layers of alum and lime sludge-treated soil profiles may be due to movement in these coarser textured soils. The higher contents of Fe in the iron sludge-treated soil may be due to movement and accumulation of Fe in the Bt horizon or to previous pedogenetic accumulation (Figure A-6).

The influence of pedogenetic horizons on amounts of NH_4-oxalate-extractable Fe is illustrated in Figure A-6. If the high Fe content of IIICk and VCk horizons of the lime sludge soil profile were nearer the surface in a sludge-treated field, one might expect greater movement than had occurred.

The NH_4-oxalate-extracted Fe was highest in the 0-6 inch layer of the sludge-treated soil profiles (Figure A-10). The Fe contents of the rest of profiles fall between the Fe contents of the two check profiles (Figure A-10). In fields such as the Milton plots, movement may have occurred but it cannot be proven from these data.

NH_4-oxalate-extractable Al

NH_4-oxalate-extractable Al is also considered to be complexed with organic matter. The greater quantities of NH_4-oxalate-extractable Al in the 0-6 inch layers is marked in sludge-treated soil profiles, Elora (Figure A-3), Cambridge (Figure A-7) and Milton (Figure A-11). There appears to be movement of sludge-applied Al to the 12 inch depth in the Elora soil profiles (Figure A-3), to the 18 inch depth in the Cambridge soil profiles (Figure A-7) and the 12 inch depth of the Milton soil profiles (Figure A-11). Below these depths in all three plots the quantities of NH_4-oxalate-extractable Al in the sludge-treated soil profiles are similar to those found in the check soil profiles (Figures A-3, A-7 and A-11).

NH_4-oxalate-extractable Mn

The profile distributions of NH_4-oxalate-extractable Mn in all profiles studied (Tables A-19 to A-27) did not show any marked increase compared to the check profiles (Departments of Land Resource Science and Microbiology, University of Guelph, 1975).

Na-dithionite-Extractable Fe, Al and Mn

Na-dithionite-extractable Fe

Na-dithionite-extractable cations are considered to be largely in oxide of hydroxide forms. The Na-dithionite-extractable Fe in the 0-6 inch layers of the sludge-treated soil profiles was less or equal to the check soil profiles, Elora (Figure A-4), Cambridge (Figure A-8) and Milton (Figure A-12). This leads to the conclusion that the Fe from the sludges is largely in organic complexes even after two years.

Na-dithionite-extractable Al and Mn

The Na-dithionite-extractable Al and Mn were similar in soils treated with each sludge in each area, Elora (Tables A-19 to A-21), Cambridge (Tables A-22 to A-24) and Milton (Tables A-25 to A-27). These values were also similar to those in the check profiles (Departments of

Land Resource Science and Microbiology, University of Guelph, 1975). These data correspond to the Fe data.

CONCLUSIONS

Constituents from the iron, alum and lime sludge applications at high rates (1600 kg/ha N) were detectable by routine soil analyses. Iron and aluminum from sludges appeared to remain in organic complexes for several years after applications to soils. These Fe and Al complexes moved below the plow layer within two years. Calcium carbonate from sludges accumulated in the surface horizons. The lime sludges appeared to increase earthworm activity.

Similar work should be done on soils from plots which have received different rates of sludge for 8 to 10 years. From such a study rates of movement could be established.

LITERATURE CITED

Canada Department of Agriculture. The System of Soil Classification for Canada, 1974.

Departments of Land Resource Science and Microbiology (University of Guelph). Land Disposal of Sewage Sludge, Vol. II. Research Report No. 24, Chap. 7, Soil Characterization. Canada-Ontario Agreement on the Great Lakes Water Quality, Environment Canada, 1975.

Departments of Land Resource Science and Microbiology (University of Guelph). Land Disposal of Sewage Sludge, Vol. III. Research Report No. 35, Chap. 7, Soil Characterization. Canada-Ontario Agreement on the Great Lakes Water Quality, Environment Canada, 1976.

Jackson, M.L. Soil Chemical Analysis. Prentice-Hall Inc., Englewood Cliffs, N.J., 498 pp., 1958.

Kilmer, V.J. and Alexander, L.T. Methods of making mechanical analysis of soils. Soil Sci. 68: 15-24, 1949.

Protz, R., Cation distribution in soils as related to sewage sludge disposal on land. Sludge Handling and Disposal Seminar. Conference Proceedings No. 2: 192-206. Canada-Ontario Agreement on Great Lakes Water Quality, Environment Canada, 1974.

Raad, A.T., R. Protz and R.L. Thomas, Determination of Na-dithionate and NH_4-oxalate-extractable Fe, Al and Mn in soils by Atomic Absorption Spectroscopy. Can. J of Soil Sci. 49: 89-94, 1969.

Tyner, E. The use of sodium metaphosphate for the dispersion of soils for mechanical analysis. Soil Sci. Soc. Amer. Proc. 4: 106-133, 1939.

Walker, P.H. Soil and geomorphic history in selected areas of the Cary till, Iowa. Unpublished Ph.D. thesis, Iowa State University, Ames, Iowa, 1965.

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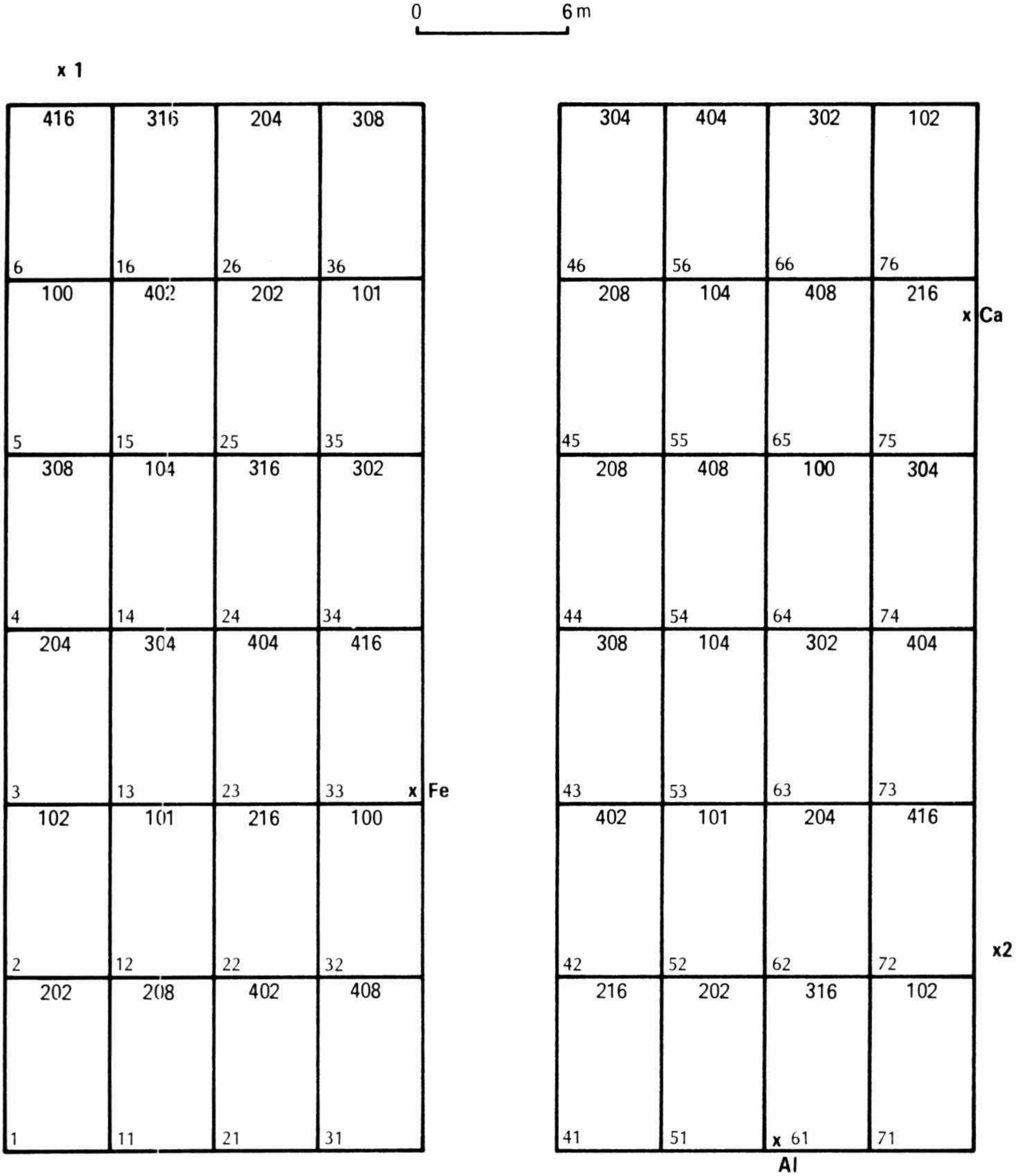

FIGURE A-1. PLOT LAYOUT, REPLICATE LOCATION AND SOIL PROFILE LOCATION ON THE ELORA CORN PLOTS.

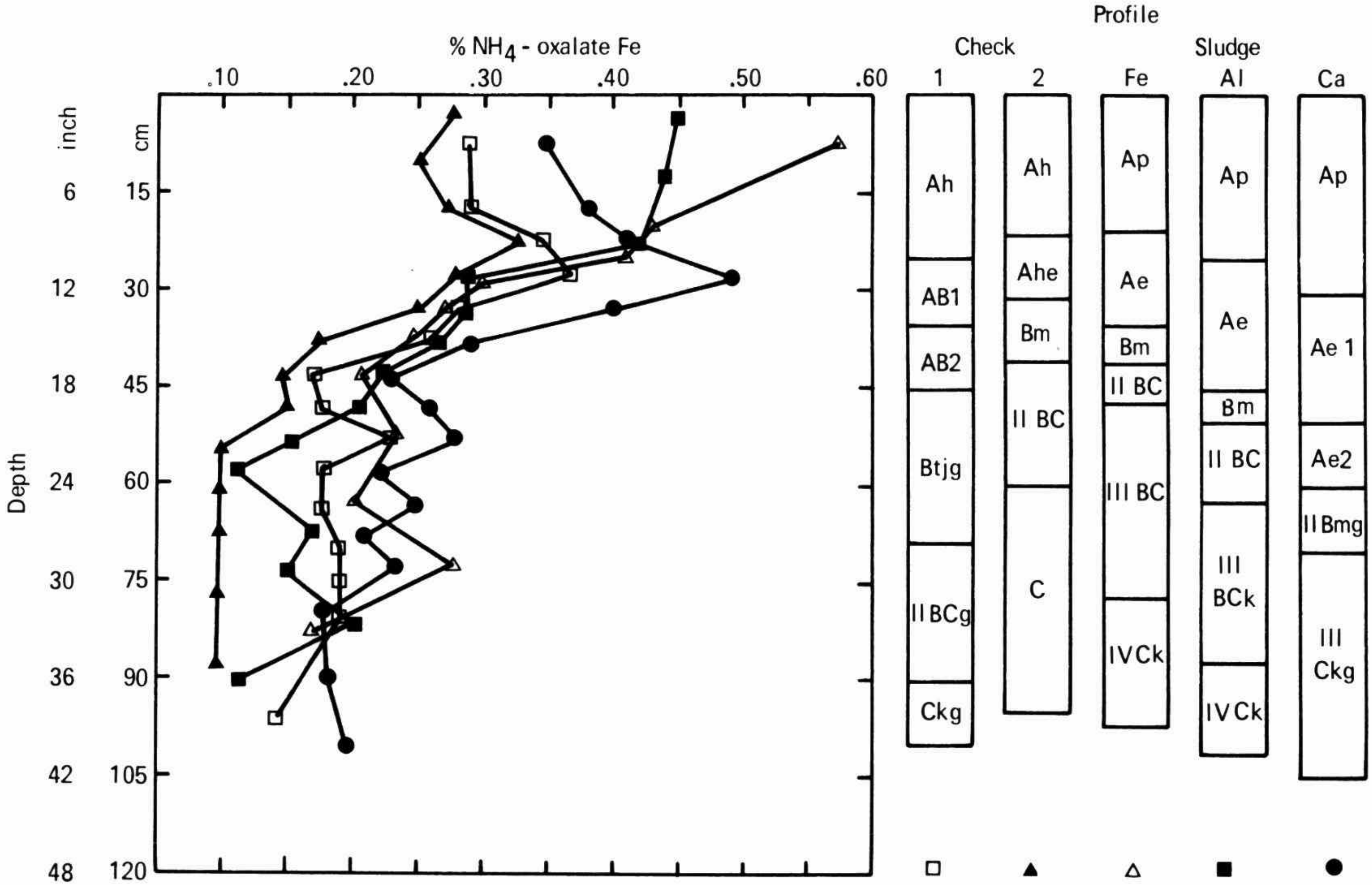

FIGURE A-2. DISTRIBUTION OF NH_4-OXALATE-EXTRACTABLE Fe WITH DEPTH IN TWO CHECK AND THREE SLUDGE TREATED SOIL PROFILES FROM THE ELORA CORN PLOTS.

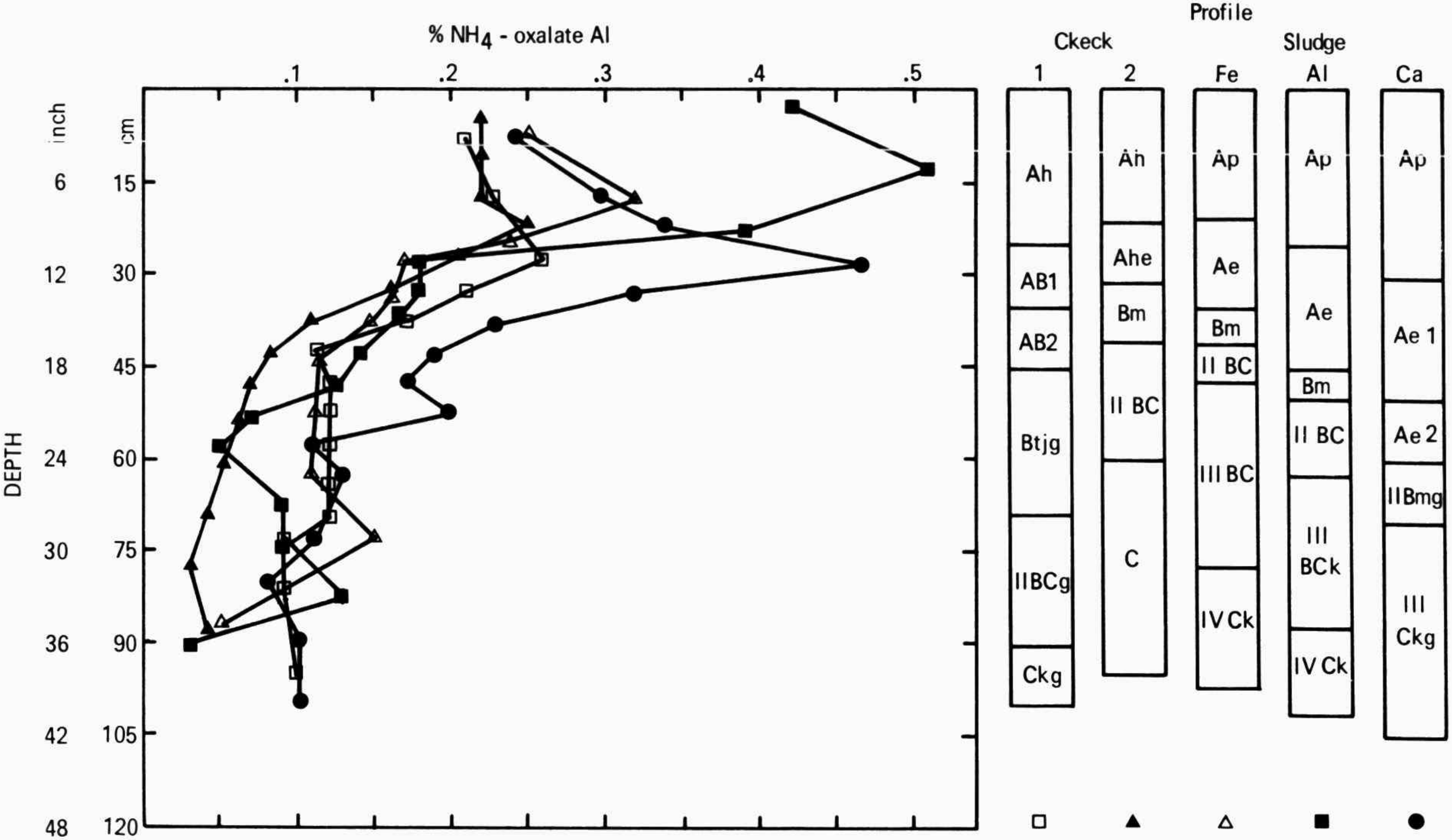

FIGURE A-3. DISTRIBUTION OF NH_4-OXALATE-EXTRACTABLE Al WITH DEPTH IN TWO CHECK AND THREE SLUDGE TREATED SOIL PROFILES FROM THE ELORA CORN PLOTS.

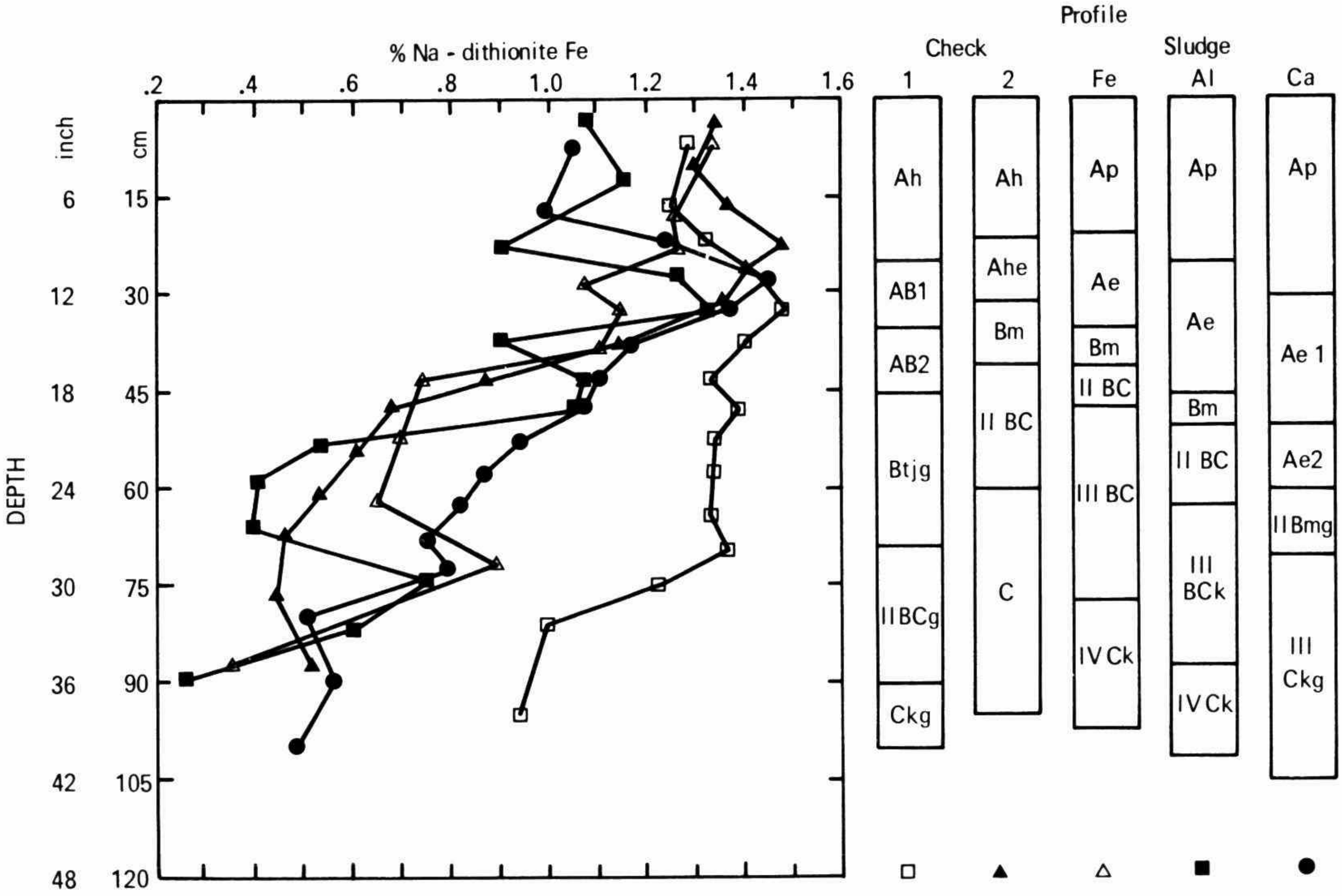

FIGURE A-4. DISTRIBUTION OF Na-DITHIONITE-EXTRACTABLE Fe WITH DEPTH IN TWO CHECK AND THREE SLUDGE TREATED SOIL PROFILES FROM ELORA CORN PLOTS.

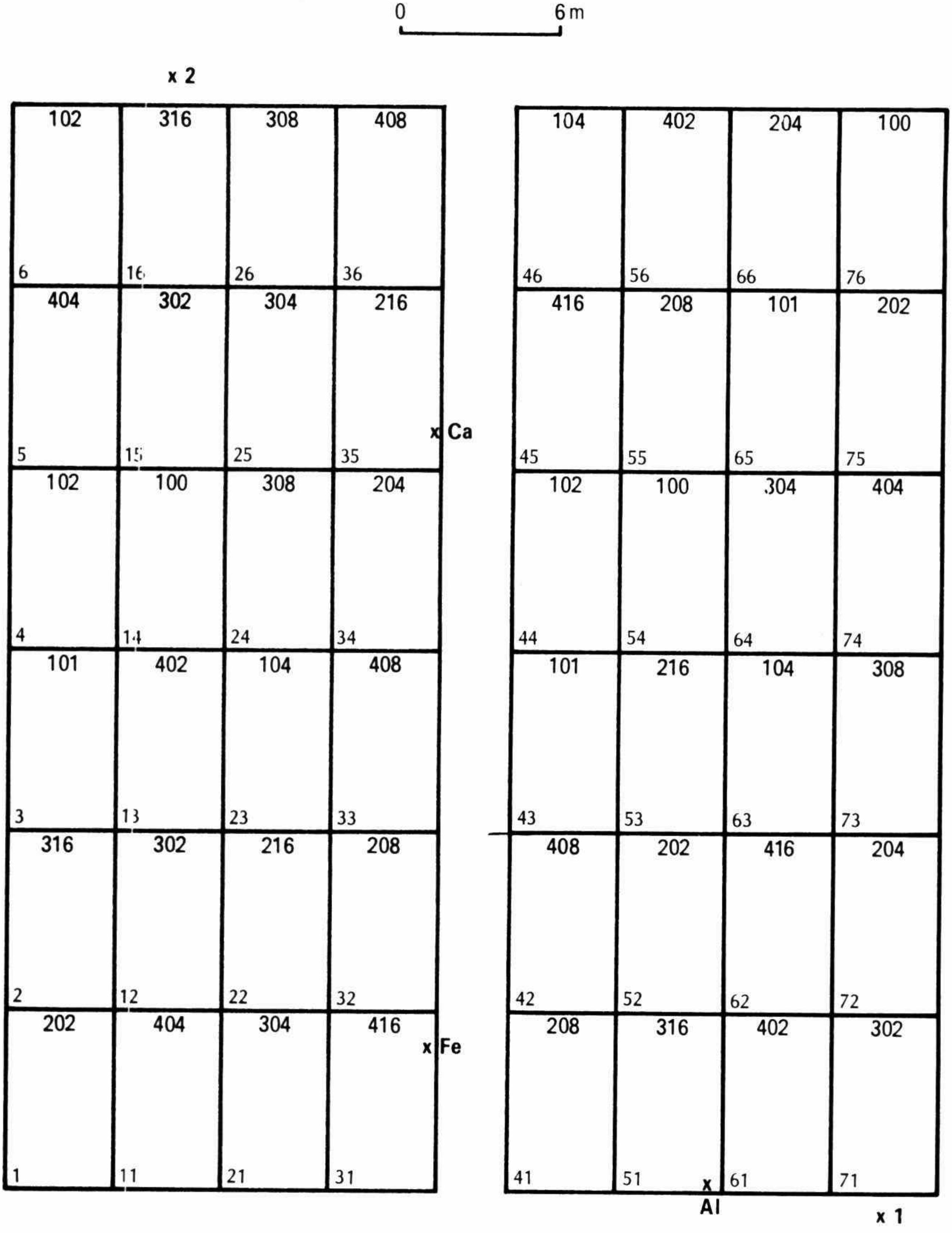

FIGURE A-5. PLOT LAYOUT, REPLICATE LOCATION AND SOIL PROFILE LOCATION ON THE CAMBRIDGE CORN PLOTS.

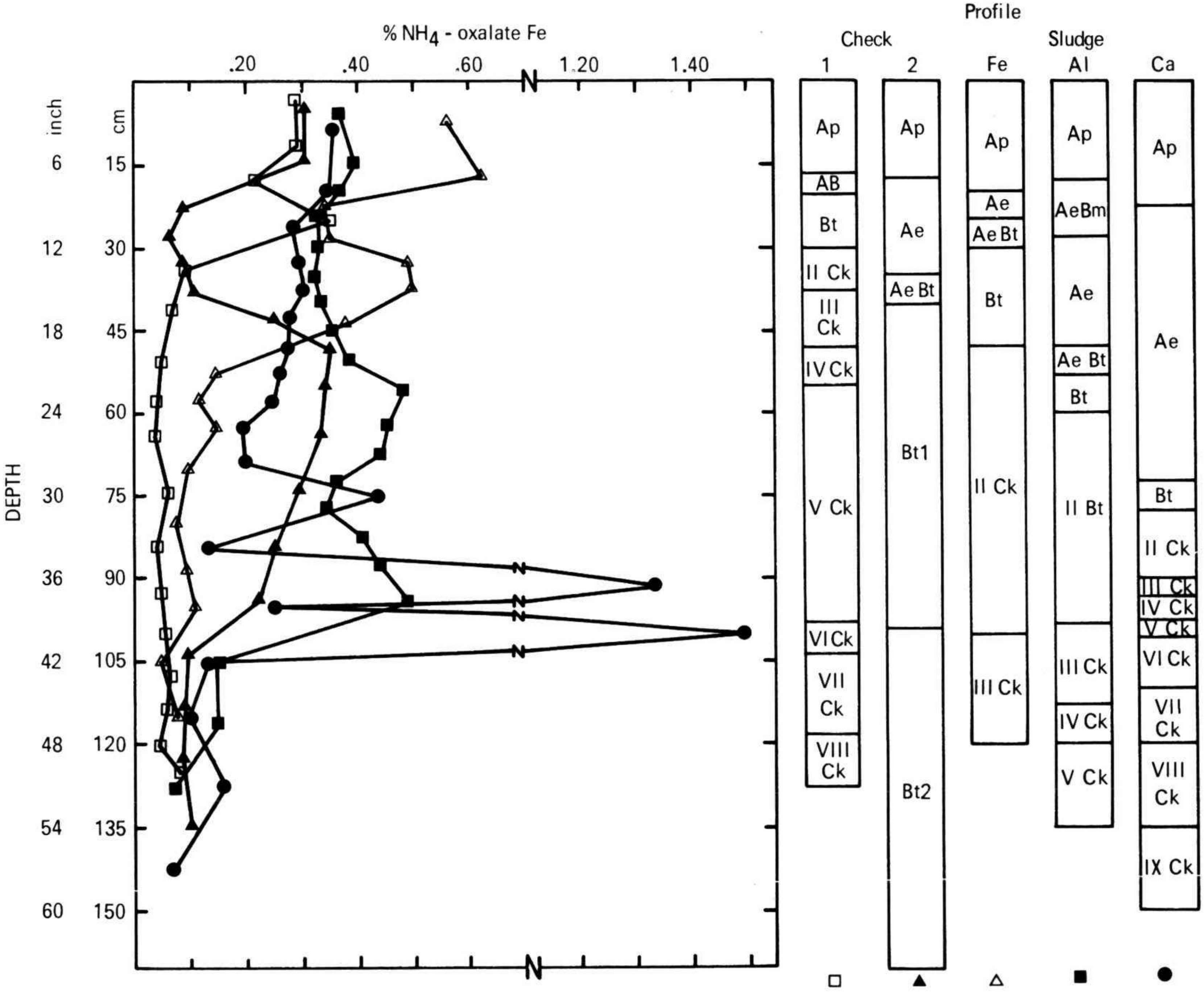

FIGURE A-6. DISTRIBUTION OF NH_4-OXALATE-EXTRACTABLE Fe WITH DEPTH IN THE TWO CHECK AND THREE SLUDGE TREATED SOIL PROFILES FROM THE CAMBRIDGE CORN PLOTS.

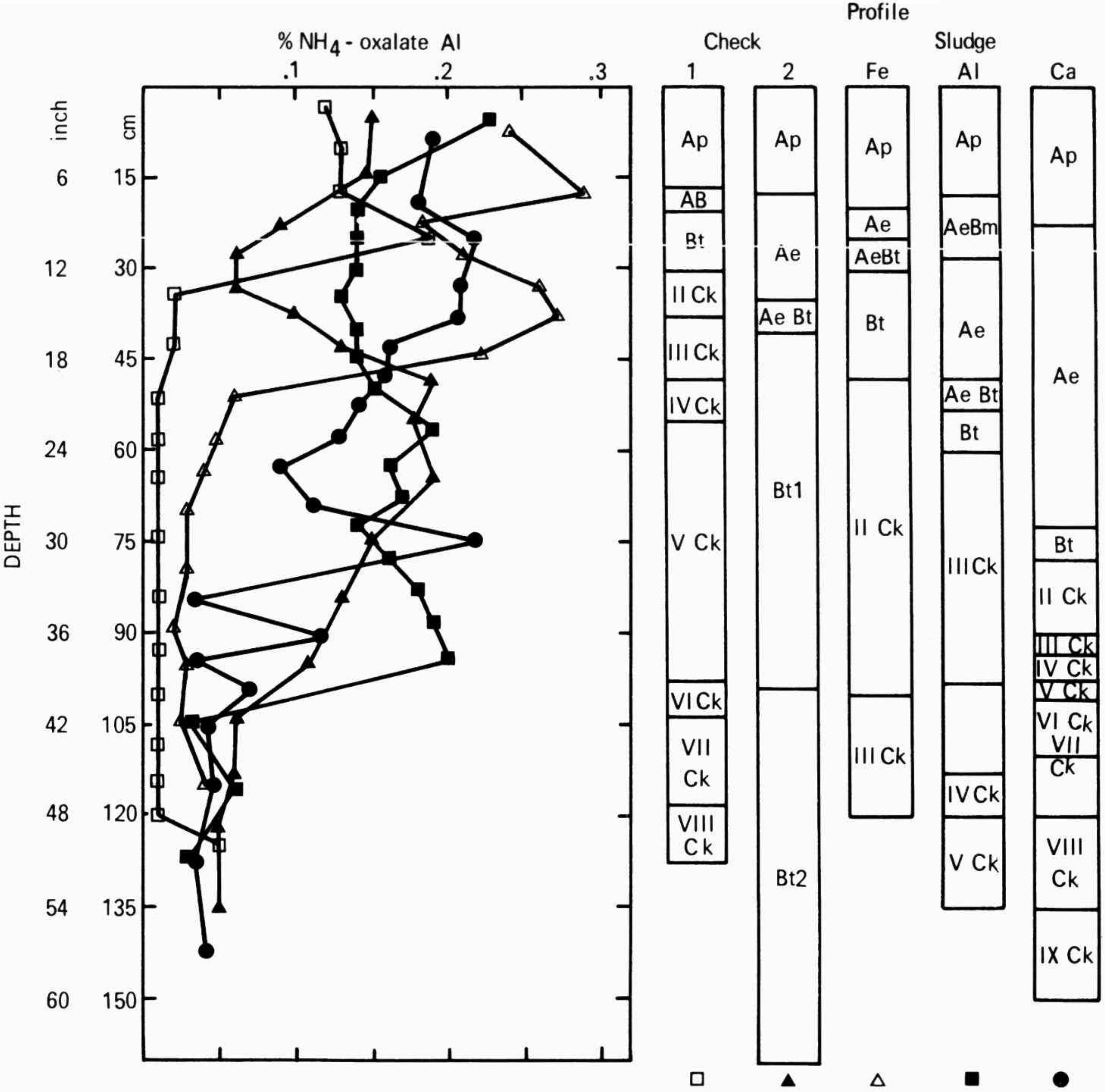

FIGURE A-7. DISTRIBUTION OF NH_4-OXALATE-EXTRACTABLE Al WITH DEPTH IN TWO CHECK AND THREE SLUDGE TREATED SOIL PROFILES FROM THE CAMBRIDGE CORN PLOTS.

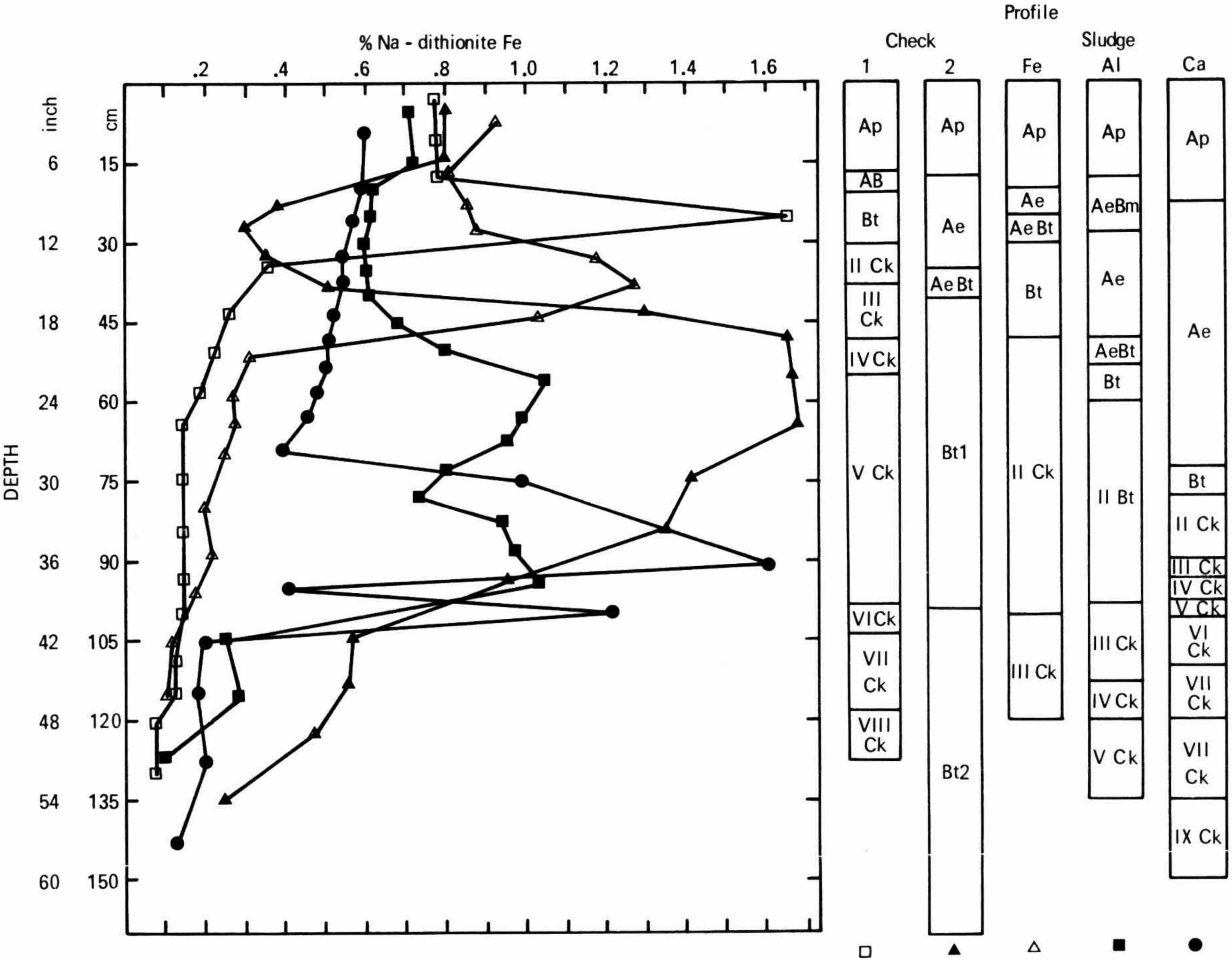

FIGURE A-8. DISTRIBUTION OF Na-DITHIONITE-EXTRACTABLE Fe WITH DEPTH IN TWO CHECK AND IN TWO CHECK AND THREE SLUDGE TREATED SOIL PROFILES FROM THE CAMBRIDGE CORN PLOTS.

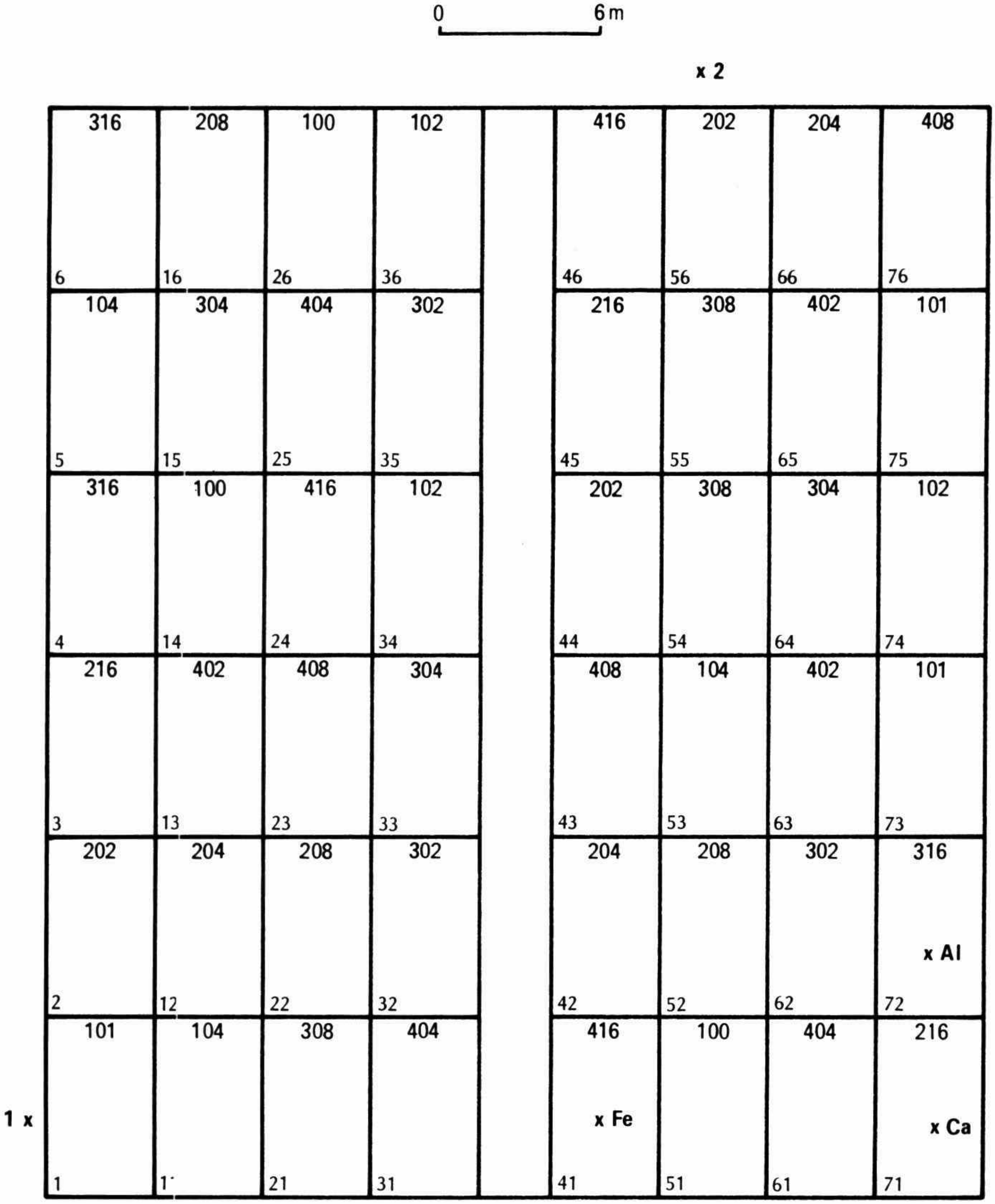

FIGURE A-9. PLOT LAYOUT, REPLICATE LOCATION AND SOIL PROFILE LOCATION ON THE MILTON CORN PLOTS.

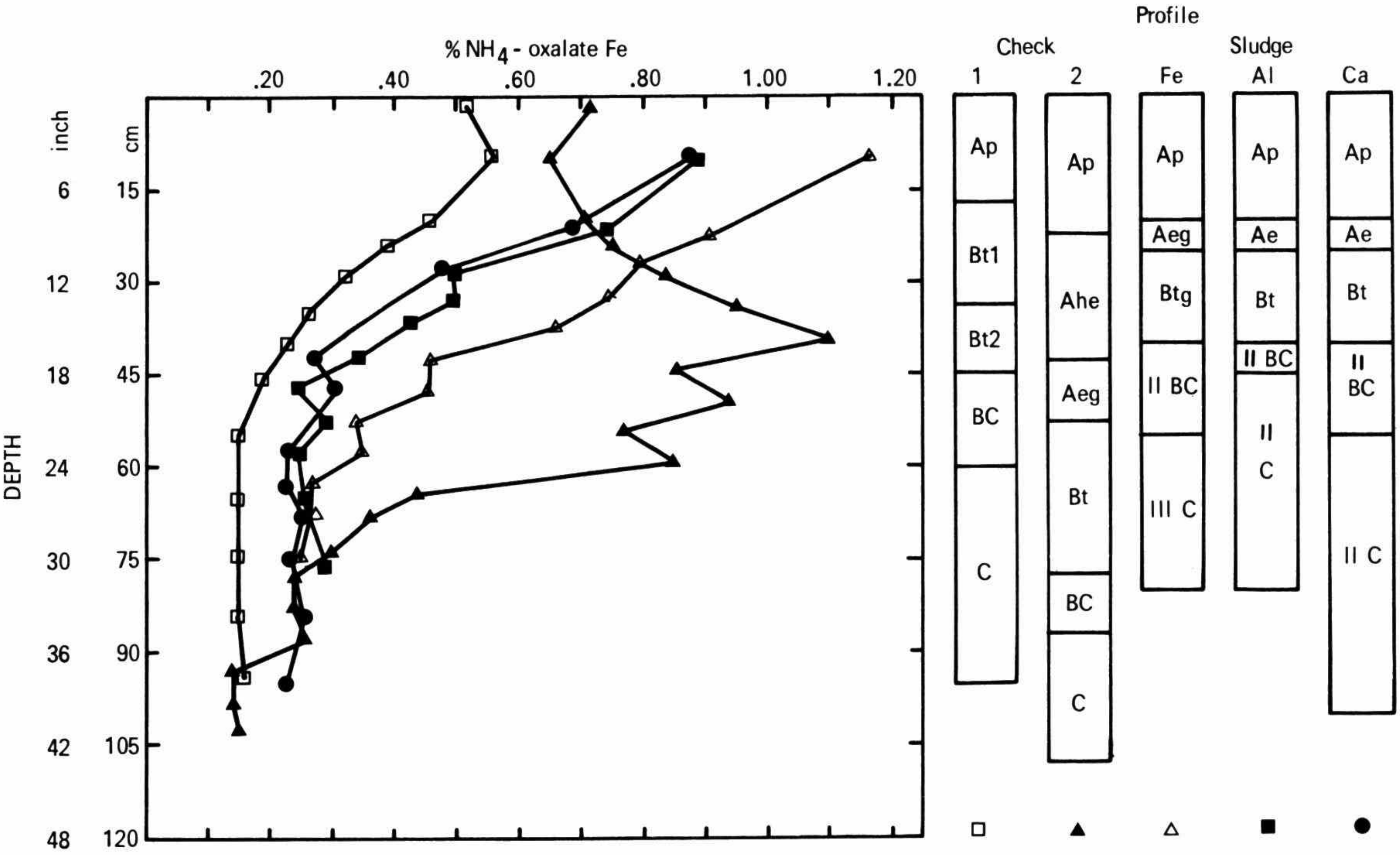

FIGURE A-10. DISTRIBUTION OF NH_4-OXALATE-EXTRACTABLE Fe WITH DEPTH IN THE TWO CHECK AND THREE SLUDGE TREATED SOIL PROFILES FROM THE MILTON CORN PLOTS.

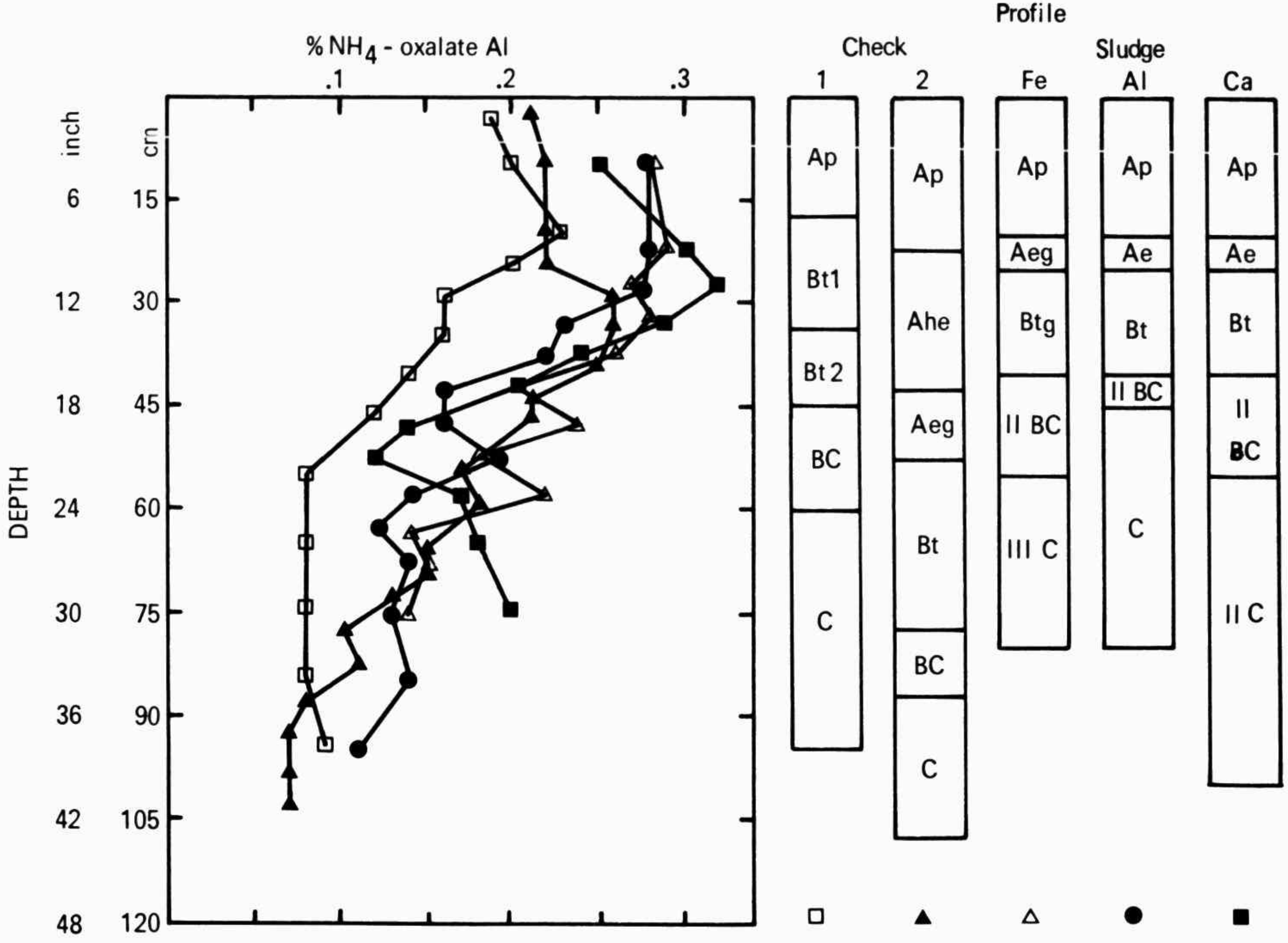

FIGURE A-11. DISTRIBUTION OF NH_4-OXALATE-EXTRACTABLE Al WITH DEPTH IN THE TWO CHECK AND THREE SLUDGE TREATED SOIL PROFILES FROM THE MILTON CORN PLOTS.

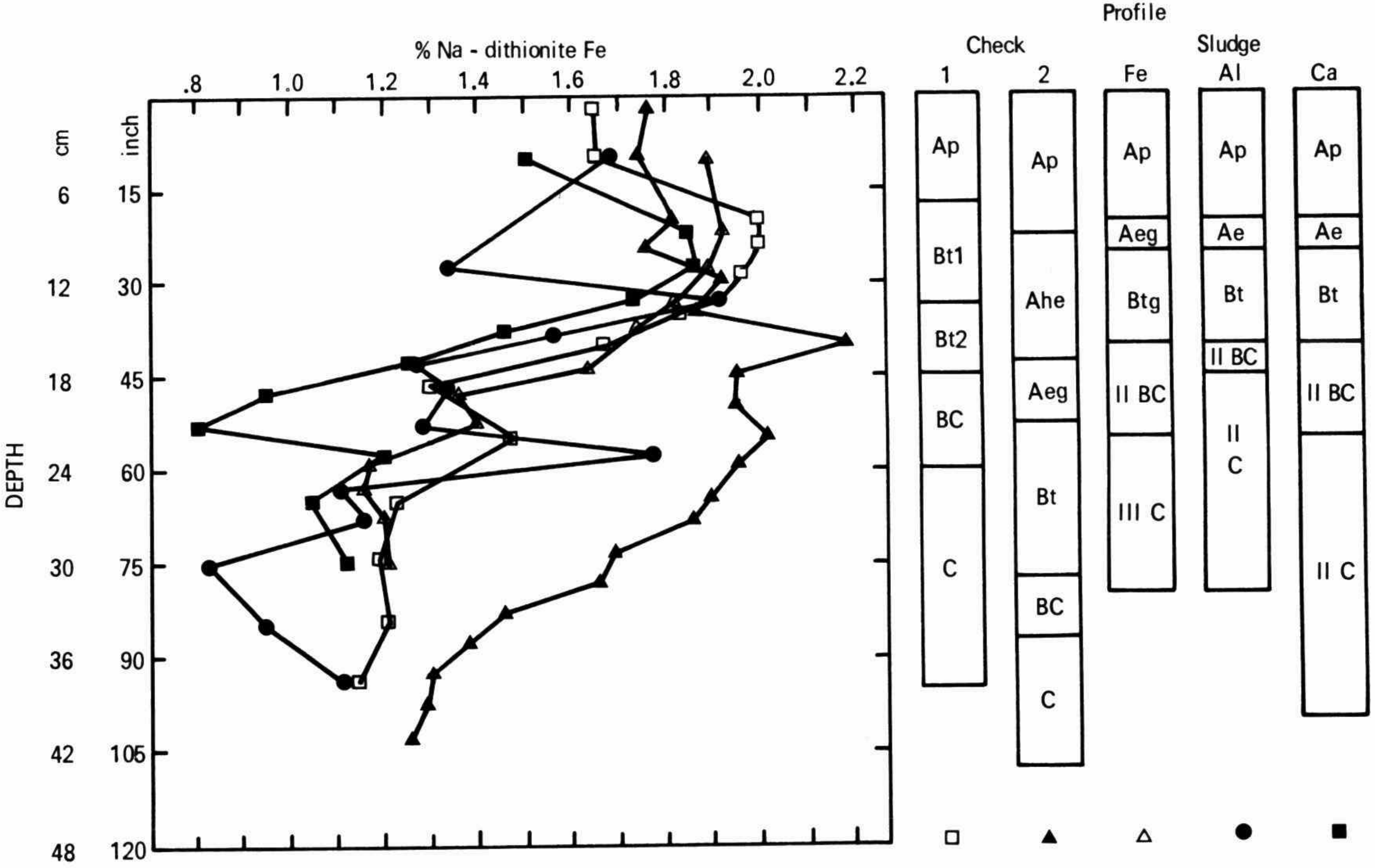

FIGURE A-12. DISTRIBUTION OF Na-DITHIONITE EXTRACTABLE Fe WITH DEPTH IN THE TWO CHECK AND THREE SLUDGE TREATED SOIL PROFILES FROM THE MILTON CORN PLOTS.

TABLE A-1. DESCRIPTION OF THE SOIL PROFILE FROM THE Fe SLUDGE ON THE ELORA CORN PLOTS.

Location: Elora Farm corn sludge plots.

Parent Material: Silt loam alluvium over till.

Landform: Lower toe slope of drumlin.

Slope: 0.5%.

Order: Brunisolic.

Great Group: Melanic Brunisol.

Sub-group: Gleyed Orthic Melanic Brunisol.

Family: Medium, mixed moderately to very strongly calcareous.

Series: Conestoga Silt Loam

Horizon	Depth Inches (cm)	Description
Ap	0 - 8 (0 - 21)	Black (10YR 2.5/1,m) and grayish brown (10YR 5/2,d) silt loam, weak coarse subangular blocky breaking to fine granular, friable (m), slightly hard (d), many earthworm channels, many roots, sharp boundary.
Ae	8 - 14 (21 - 35)	Light yellowish brown (10YR 6/4,m) with some black (10YR 2.5/1, m) and very pale brown (10YR 7/4,d) with some grayish brown (10YR 5/2,d), silt loam, weak coarse subangular blocky breaking to fine granular, friable (m), slightly hard (d), many earthworms, many roots, sharp boundary.
Bm	14 - 16 (35 - 41)	Same colors as above, silt loam, moderate medium angular blocky (stratified sands and silts) friable (m), slightly hard (d), many earthworms, few roots, sharp boundary.
II BC	16 - 19 (41 - 47)	Brownish yellow (10YR 6/6,m) with some brown (10YR 5/3,m) and yellow (10YR 7/6,d) loam, moderately subangular blocky, firm (m), very hard (d), many earthworm channels, roots on ped surfaces, gradual boundary.
III BC	19 - 30 (47 - 77)	Pink (7.5YR 7/4,m) and pinkish gray (7.5YR 7/2,d), loam, moderately strong angular blocky, firm (n), very hard (d), many earthworm channels, roots on ped surfaces, sharp boundary.
IV Ck	30 - 38 (77 - 97)	Pale brown (10YR 6/3,m) and white (10YR 8/1,d), sandy loam, massive, firm (m), slightly hard (d), many dolomitic gravels.

TABLE A-2. DESCRIPTION OF THE SOIL PROFILE FROM THE Al SLUDGE ON THE ELORA CORN PLOTS.

Location:	Elora Farm corn sludge plots.
Parent Material:	Silt loam alluvium over till.
Landform:	Lower toe slope of Drumlin.
Slope:	1%.
Order:	Brunisolic.
Great Group:	Melanic Brunisol.
Sub-group:	Gleyed Orthic Melanic Brunisol.
Family:	Medium, mixed moderately to very strongly calcareous.
Series:	Conestoga Silt Loam.

Horizon	Depth Inches (cm)	Description
Ap	0 - 10 (0 - 25)	Black (10YR 2.5/1, m) and grayish brown (10YR 5/2,d) silt loam, weak coarse subangular blocky breaking to fine granular, friable (m), slightly hard (d), few earthworm channels, many roots, sharp boundary.
Ae	10 - 18 (25 - 45)	Brownish yellow (10YR6/6,m) and yellow (10YR 7/6,d) silt loam, weak coarse subangular blocky breaking to fine granular, friable (m), slightly hard (d), many earthworm channels, few roots, sharp boundary.
Bm	18 - 20 (45 - 50)	Yellow (10YR 7/6,m) and yellow (10YR 7/6,d), silt loam, weak coarse subangular blocky breaking to fine granular, friable (m), slightly hard (d), many earthworm channels, with fine dolomitic gravels, sharp boundary.
II BCk	20 - 24 (50 - 62)	Light yellowish brown (10YR6/4,m) and very pale brown (10YR 7/3, d), sandy loam, massive, firm (m), slightly hard (d), sharp boundary.
III BCk	24 - 34 (62 - 87)	Light brown (7.5YR 6/4,m) and pinkish gray (7.5YR 7/2,d), silt loam, massive, firm (m) very hard (d), sharp boundary.
IV Ck	34 - 40 (87 - 103)	Very pale brown (10YR 7/3,m) and white (10YR 8/1,d), loam, massive, firm (m), slightly hard (d), more gravels.

TABLE A-3. DESCRIPTION OF THE SOIL PROFILE FROM THE Ca SLUDGE ON THE ELORA CORN PLOTS.

Location:	Elora farm corn sludge plots.
Parent Material:	Silt loam alluvium over till.
Landform:	Flat plain at toe of drumlin.
Slope:	0%.
Order:	Brunisolic.
Great Group:	Melanic Brunisol.
Sub-group:	Gleyed Orthic Melanic Brunisol.
Family:	Medium, mixed moderately to very strongly calcareous.
Series:	Conestoga Silt Loam.

Horizon	Depth Inches (cm)	Description
Ap	0 - 12 (0 - 30)	Black (10YR 2.5/1,m) and brown (10YR 5/3,d), silt loam, weak coarse subangular, blocky breaking to coarse granular, friable (m), very hard (d) many worm casts and many roots, gradual boundary.
Ae 1	12 - 20 (30 - 50)	Yellowish brown (10YR 5/4,m) with some very dark gray (10YR 3/1,m) and very pale brown (10YR 7/3,d) with some brown (10YR 5/3,d), silt loam, weak coarse subangular blocky breaking to coarse granular, friable (m), very hard (d), many worm casts, gradual boundary.
Ae 2	20 - 24 (50 - 60)	Yellowish brown (10YR 5/6,m) with some very dark gray (10YR 3/1,m) and very pale brown (10YR 7/3,d), with some brown (10YR 5/3,d), loam, weak coarse subangular blocky breaking coarse granular, friable (m), very hard (d), many earthworm casts, some weathered dolomites, gradual boundary.
II Bmg	24 - 28 (60 - 70)	Yellowish brown (10YR 5/6,m) some very dark gray (10YR 3/1,m) with mottles and very pale brown (10YR 7/3,d), sandy loam, weak coarse subangular blocky breaking to coarse granular, friable (m), very hard (d), some weathered dolomites, sharp boundary.
III Ckg	28 - 41 (70 - 105)	Dark brown (10YR 4/3,m) with grayish brown (10YR 5/2,m) and very pale brown (10YR 7/3,d), sandy loam, massive, friable (m), very hard (d).

TABLE A-4. DESCRIPTION OF THE SOIL PROFILE FROM THE Fe SLUDGE ON THE CAMBRIDGE CORN PLOTS.

Location:	Cambridge Farm corn sludge plots.
Parent Material:	Alluvial sands over outwash gravels.
Landform:	Undulating alluvial plain.
Slope:	2%.
Order:	Luvisolic.
Great Group:	Gray Brown Luvisolic.
Sub-group:	Brunisolic Gray Brown Luvisolic.
Family:	Coarse over coarse skeletal, mixed moderately to very strong calcareous.
Series:	Caledon sandy loam.

Horizon	Depth Inches (cm)	Description
Ap	0 - 8 (0 - 20)	Very dark gray (10YR 3/1,m) and grayish brown (10YR 5/2,d) sandy loam, weak coarse subangular blocky breaking to single grain, friable (m), slightly hard (d), few pores, few roots, sharp boundary.
Ae	8 - 10 (20 - 25)	Mixed colors, yellowish brown (10YR 5/4,m) and very dark gray (10YR 3/1,m) and pale brown (10YR 6/3,d) and grayish brown (10YR 5/2,d) sandy loam, weak coarse subangular blocky, breaking to single grain, friable (m), slightly hard (d), few pores and roots, some earthworm casts, gradual boundary.
Ae (Mixed with Bt)	10 - 12 (25 - 30)	Mixed colors, dark brown (7.5YR 4/4,m) and yellowish brown (10YR 5/4,m), brown (7.5YR 5/4,d) and light yellowish brown (10YR 6/4,d), sandy loam, weak coarse subangular blocky breaking to single grain, friable (m), slightly hard (d), few pores and roots, some earthworm casts, some dolomite pebbles, gradual boundary.
Bt	12 - 19 (30 - 48)	Dark brown (7.5YR 4/4,m) and brown (7.5YR 5/4,d) sandy loam, weak coarse subangular blocky breaking single grain, friable (m), slightly hard (d), few pores and roots, some earthworm casts, some dolomite pebbles, abrupt boundary.
II Ck	19 - 40 (48 - 102)	Very pale brown (10YR 7/3,m) and very pale brown (10YR 8/3, d)coarse sand, single grain, loose (m), loose (d), gravelly, some $CaCO_3$ accumulation, abrupt boundary.
III Ck	40 - 48 (102 - 122)	Light gray (10YR 7/2,m) and white (10YR 8/2,d), very fine sand, single grain, loose (m), loose (d).

TABLE A-5. DESCRIPTION OF THE SOIL PROFILE FROM Al SLUDGE ON THE CAMBRIDGE CORN PLOTS.

Location:	Cambridge Farm corn sludge plots.
Parent Material:	Alluvial sand over outwash gravels.
Landform:	Undulating alluvial plain.
Slope:	2%.
Order:	Luvisolic.
Great Group:	Gray Brown Luvisolic.
Sub-group:	Brunisolic Gray Brown Luvisolic.
Family:	Coarse over coarse-skeletal, mixed moderately to very strong calcareous.
Series:	Caledon Sandy Loam.

Horizon	Depth Inches (cm)	Description
Ap	0 - 7 (0 - 17)	Very dark grayish brown (10YR 3/2,m), brown (10YR 5/3,d), sandy loam, weak coarse subangular blocky, breaking to single grain, friable (m), hard (d), gray precipitate on surface of peds, abrupt boundary.
Ae (Mixed with Bm)	7 - 9 (17 - 23)	Yellowish brown (10YR 5/6,m), light yellowish brown (10YR 6/4,d), sandy loam, weak coarse subangular blocky breaking to single grain, friable (m), slightly hard (d), gray precipitate on surface of peds, abrupt boundary.
Ae	9 - 19 (23 - 48)	Brown (10YR 5/3,m) very pale brown (10YR 7/4,d), sandy loam, weak coarse subangular blocky breaking to single grain, friable (m), slightly hard (d), few roots and pores, few earthworm casts, gradual boundary.
Ae (Mixed with Bt)	19 - 21 (48 - 53)	Mixed colors brown (10YR 5/3,m) and dark brown (7.5YR 4/4,m), very pale brown (10YR 7/4,d) and brown (7.5YR 5/3,d), sandy loam, weak coarse subangular blocky breaking to single grain; friable (m), slightly hard (d), few roots and pores, few earthworm casts, gradual boundary.
Bt	21 - 24 (53 - 61)	Dark brown (7.5YR 4/4,m), brown (7.5YR 5/3,d), sandy loam, weak coarse subangular blocky breaking to single grain, friable (m), slightly hard (d), few roots, sharp boundary.

TABLE A-5. (CONT'D)

Horizon	Depth Inches (cm)	Description
II Bt	24 - 39 (61 - 99)	Dark brown (7.5YR 4/4,m) strong brown (7.5YR 5/6,d) loamy sand, weak coarse subangular blocky breaking to single grain, very friable (m), soft (d), few roots, gradual boundary.
III Ck	39 - 45 (99 - 114)	Very pale brown (10YR 7/3,m) and very pale brown (10YR 7/3,d), coarse sand, single grain, loose (m), loose (d), no roots, gravels, sharp boundary.
IV Ck	45 - 48 (114 - 122)	Very pale brown (10YR 7/3,m) and yellowish brown (10YR 5/4,m), white (10YR 8/2,d) and light yellowish brown (10YR 6/4,d), very fine sand, weak coarse subangular blocky breaking to single grain, very friable (m), soft (d), few roots, abrupt boundary.
V Ck	48 - 54 (122 - 137)	Very pale brown (10YR 7/3,m), white (10YR 8/2,d) fine sand, single grain, very friable (m), soft (d).

TABLE A-6. DESCRIPTION OF THE SOIL PROFILE FROM THE Ca SLUDGE ON THE CAMBRIDGE CORN PLOTS.

Location:	Cambridge Farm corn sludge plots.
Parent Material:	Alluvial sands over outwash gravels.
Landform:	Undulating alluvial plain.
Slope:	0.5%.
Order:	Luvisolic.
Great Group:	Gray Brown Luvisolic.
Sub-group:	Brunisolic Gray Brown Luvisolic.
Family:	Coarse over coarse-skeletal mixed, moderately to very strong calcareous.
Series:	Caledon Sandy Loam.

Horizon	Depth Inches (cm)	Description
Ap	0 - 9 (0 - 23)	Mixed colors very dark gray (10YR 3/1,m) and yellowish brown (10YR 5/6,m), brown (10YR 5/3,d) and yellow (10YR 8/6,d), sandy loam, weak coarse subangular blocky breaking to single grain, friable (m), hard (d), few roots and pores, earthworm casts, gradual boundary.
Ae	9 - 29 (23 - 73)	Yellowish brown (10YR 5/6,m), very pale brown (10YR 7/4,d) loamy sand, weak coarse subangular blocky breaking to single grain, friable (m), slightly hard (d), few roots, many earthworm channels, abrupt boundary.
Bt	29 - 31 (73 - 79)	Dark brown (7.5YR 4/4,m), dark brown (7.5YR 4/4,d), sandy loam, weak coarse subangular blocky breaking to single grain, friable (m), hard (d), few roots, many earthworm channels, with weathered dolomites, sharp boundary.
II Ck	31 - 36 (79 - 91)	Pale brown (10YR 6/3, m), very pale brown (10YR 7/3,d), sand, single grain, loose (m), loose (d), sharp boundary.
III Ck	36 - 37 (91 - 94)	Dark brown (7.5YR 4/4,m), dark brown (7.5YR 4/4,d), loamy sand, weak medium, subangular blocky, breaking to single grain, friable (m), slightly hard (d), heavy mineral layer, sharp boundary.
IV Ck	37 - 39 (94 - 99)	Light yellowish brown (10YR 6/4,m), very pale brown (10YR 7/3, d), sand, single grain, loose (m), slightly hard (d), sharp boundary.

TABLE A-6. (CONT'D)

Horizon	Depth Inches (cm)	Description
V Ck	39 - 40 (99 - 102)	Dark brown (7.5YR 3/2,m), brown (7.5YR 4/4) sand, weak fine subangular blocky breaking to single grain, friable (m), slightly hard (d), heavy mineral layer, sharp boundary.
VI Ck	40 - 44 (102 - 112)	Light gray (10YR 7/2,m), white (10YR 8/2,d) coarse sand, single grain, loose (m), loose (d), sharp boundary.
VII Ck	44 - 48 (112 - 122)	Light gray (10YR 7/1,m), white (10YR 8/1,d), very fine sand, single grain, loose (m), loose (d), sharp boundary.
VIII Ck	48 - 54 (122 - 137)	Light gray (10YR 7/1,m), white (10YR 8/1,d), very fine sand, single grain, loose (m), loose (d), fine heavy mineral bands, sharp boundary.
IX Ck	54 - 60 (137 - 152)	Light gray (10YR 7/1,m), white (10YR 8/1,d) very fine sand, single grain, loose (m), loose (d).

TABLE A-7. DESCRIPTION OF THE SOIL PROFILE FROM THE Fe SLUDGE ON THE MILTON CORN PLOTS.

Location:	Milton corn sludge plots.
Parent Material:	Silty clay loam alluvium over glacial till.
Landform:	Till plain.
Slope:	1%.
Order:	Luvisolic.
Great Group:	Gray Brown Luvisolic.
Sub-group:	Brunisolic Gray Brown Luvisolic.
Family:	Fine, mixed, acid to neutral, weakly calcareous.
Series:	Oneida Clay Loam.

Horizon	Depth Inches (cm)	Description
Ap	0 - 8 (0 - 20)	Very dark grayish brown (10YR 3/2,m) and pale brown (10YR 6/3,d), clay loam strong coarse subangular blocky, firm (m), very hard (d), many earthworm casts, gradual boundary.
Aeg	8 - 10 (20 - 25)	Very dark grayish brown (10YR 3/2,m) with brownish yellow (10YR 6/6,m) mottles and pale brown (10YR 6/3,d) with yellow (10YR 7/6,d) mottles, clay loam, strong coarse subangular blocky, firm (m), very hard (d), many earthworm casts, gradual boundary.
Btg	10 - 16 (25 - 40)	Dark brown (7.5YR 4/4,m) with brownish yellow (10YR 6/6,m) mottles and pinkish gray (7.5YR 7/2, d) with yellow (10YR 7/6,d) mottles, clay loam, strong coarse subangular blocky, firm (m), very hard (d), many earthworm casts, Mn stains, gradual boundary.
II BC	16 - 22 (40 - 55)	Dark brown (7.5YR 4/4,m) with gray (2.5Y 6/1,m) plus yellowish red (5YR 4/6,m) and olive gray (5Y 4/2,m) shales and brown (7.5YR 4/2,d) with light gray (2.5Y 7/1,d) plus yellowish red (5YR 4/6,d) and olive gray (5Y 4/2,d) shales, silty clay loam, strong angular blocky, firm (m), very hard (d), Mn stains, gradual boundary.
III C	22 - 30 (55 - 80)	Dark brown (7.5YR 4/4,m) with gray (2.5Y 6/1,m) plus yellowish red (5YR 4/6,m) and olive gray (5Y 4/2,m) shales and brown (7.5YR 4/2,d) with light gray (2.5Y 7/1,d) plus yellowish red (5YR 4/6,d) and olive gray (5Y 4/2,d) shales, silty clay loam, strong angular blocky, firm (m), very hard (d), Mn stains, gradual boundry.

TABLE A-7. (CONT'D)

Horizon	Depth Inches (cm)	Description
	Sub profile from opposite side of pit	
Aeg	7 - 9 (18 - 21)	Dark brown (10YR 3/3,m) with brownish yellow (10YR 6/6,m) mottles and pale brown (10YR 6/3,d) with yellow (10YR 7/6,d), silty clay loam, strong coarse subangular blocky, firm (m), very hard (d), sharp boundary.
Ahb	9 - 12 (21 - 30)	Black (7.5YR 2/0,m) with dark grayish brown (10YR 4/2,m) and gray (7.5YR 5/1,d) and very pale brown (10YR 7/3,d), clay, strong coarse granular breaking to fine granular, friable (m), slightly hard (d), sharp boundary.
II Ckg	12 - 14 (30 - 36)	Dark brown (7.5YR 3/2,m) with reddish brown (5YR 5/4,m) mottles and very pale brown (10YR 7/3,d) with reddish yellow (5YR 6/6,d) mottles, clay, strong coarse subangular blocky, firm (m), very hard (d).

TABLE A-8. DESCRIPTION OF THE SOIL PROFILE FROM THE A1 SLUDGE ON THE MILTON CORN PLOTS.

Location:	Milton corn sludge plots.
Parent Material:	Silty clay loam alluvium over glacial till.
Landform:	Till plain.
Slope:	0.5%.
Order:	Luvisolic.
Great Group:	Gray Brown Luvisolic.
Sub-group:	Brunisolic Gray Brown Luvisolic.
Family:	Fine, mixed, acid to neutral, weakly calcareous.
Series:	Oneida Silty Loam.

Horizon	Depth Inches (cm)	Description
Ap	0 - 8 (0 - 20)	Dark grayish brown (10YR 4/2,m) and light brownish gray (10YR 6/2,d), silty clay loam, strong coarse subangular blocky, firm (m), very hard (d), many earthworms, corn stalks, sharp boundary.
Ae	8 - 10 (20 - 25)	Grayish brown (10YR 5/2,m) and light brownish gray (10YR 6/2,d), silty clay, strong coarse subangular blocky, firm (m), very hard (d), many fine faint mottles, earthworm channels, gradual boundary.
Bt	10 - 16 (25 - 40)	Dark brown (7.5YR 4/4,m) and light brownish gray (10YR 6/2,d), silty clay loam, strong medium angular blocky, firm (m), very hard (d), many fine faint mottles, red and green shales, gradual boundary.
II BC	16 - 18 (40 - 45)	Dark brown (7.5YR 4/4,m) with yellowish red (5YR 4/6,m) shales, and light brownish gray (10YR 6/2,d), silt loam, strong medium angular blocky, firm (m), very hard (d), many fine faint mottles, with green and red shales, banded, earthworm channels, gradual boundary.
II C	18 - 32 (45 - 80)	Dark brown (7.5YR 4/4,m) with yellowish red (5YR 4/6,m) with olive gray (5Y 4/2,m) shales and pinkish gray (10YR 7/2,d), with light reddish brown (5YR 6/4,d) with olive gray (5Y 4/2,d) shales, silt loam, strong medium angular blocky, firm (m), very hard (d), earthworm channels, watertable at 28 inches (70 cm).

TABLE A-9. DESCRIPTION OF THE SOIL PROFILE FROM THE Ca SLUDGE ON THE MILTON CORN PLOTS.

Location:	Milton corn sludge plots.
Parent Material:	Silty clay loam alluvium over glacial till.
Landform:	Till plain.
Slope:	0.5%.
Order:	Luvisolic.
Great Group:	Gray Brown Luvisolic.
Sub-group:	Brunisolic Gray Brown Luvisolic.
Family:	Fine, mixed, acid to neutral, weakly calcareous.
Series:	Oneida Silty Clay Loam.

Horizon	Depth Inches (cm)	Description
Ap	0 - 8 (0 - 20)	Dark grayish brown (10YR 4/2,m), light brownish gray (10YR 6/2,d), silty clay loam, strong coarse subangular blocky, firm (m), very hard (d), many earthworm channels, corn stalks, sharp boundary.
Ae	8 - 10 (20 - 25)	Grayish brown (10YR 5/2,m), and light brownish gray (10YR 6/2,d), silty clay, strong coarse sub-angular blocky, firm (m), very hard (d), many earthworm channels, corn stalks, gradual boundary.
Bt	10 - 16 (25 - 40)	Dark brown (7.5YR 4/4,m) and some gray (2.5Y 6/1, m), plus some yellowish red (5YR 4/6,m) shales and light yellowish gray (10YR 6/2,d), silty clay, strong medium angular blocky, firm (m), very hard (d), many earthworm channels, sharp boundary.
II BC	16 - 22 (40 - 55)	Dark brown (7.5YR 4/4,m) with gray (2.5Y 6/1,m) plus yellowish red (5YR 4/6,m) and olive gray (5Y 4/2,m) shales, and brown (7.5YR 5/2,d) with light gray (2.5Y 7/1,d) plus yellowish red (5YR 4/6,m) and olive gray (5Y 4/2,m) shales, silt loam, strong medium angular blocky, firm (m), very hard (d), good argillans, some gravels, watertable at 18 inches (45 cm), gradual boundary.
II C	22 - 40 (55 - 100)	Pinkish gray (7.5YR 7/2,m) with yellowish red (5YR 4/6,m) and olive gray (5Y 4/2,m) shales and pinkish gray (7.5YR 7/2,d), silt loam, strong medium angular blocky, firm (m), very hard (d), some argillans.

TABLE A-10. PARTICLE SIZE DISTRIBUTION OF THE SOIL PROFILE FROM THE Fe SLUDGE ON THE ELORA CORN PLOTS.

Horizon	Depth Inches (cm)	% of < 2000 μ fraction			
		<2	2 - 20	20 - 50	50 - 2000
Ap	0 - 6 (0 - 15)	19.9	23.5	31.1	25.5
	6 - 8 (15 - 12)	19.7	25.8	31.0	23.5
Ae	8 - 10 (21 - 26)	18.4	24.9	38.7	18.0
	10 - 12 (26 - 30)	17.4	23.0	40.1	19.5
	12 - 14 (30 - 35)	16.3	22.4	37.3	24.1
Bm	14 - 16 (35 - 41)	15.7	18.9	39.3	26.2
IIBC	16 - 19 (41 - 47)	15.8	17.9	23.5	42.7
IIIBC	19 - 22 (47 - 57)	19.0	23.1	16.5	41.5
	22 - 26 (57 - 67)	19.1	31.1	18.3	31.5
	26 - 30 (67 - 77)	21.5	33.8	14.4	30.3
IVCk	30 - 38 (77 - 97)	7.5	12.0	15.9	64.6

TABLE A-11. PARTICLE SIZE DISTRIBUTION OF THE SOIL PROFILE FROM THE Al SLUDGE ON THE ELORA CORN PLOTS.

Horizon	Depth Inches (cm)	% of < 2000 μ fraction			
		<2	2 - 20	20 - 50	50 - 2000
Ap	0 - 2 (0 - 5)	20.7	26.6	30.7	22.0
	2 - 8 (5 - 20)	18.2	27.9	33.5	20.4
	8 - 10 (20 - 25)	20.1	28.3	30.3	21.3
Ae	10 - 12 (25 - 30)	18.6	22.8	40.7	17.8
	12 - 14 (30 - 35)	17.8	22.1	43.5	16.5
	14 - 16 (35 - 40)	16.5	21.0	43.2	19.3
	16 - 18 (40 - 45)	15.9	21.2	39.2	23.7
Bm	18 - 20 (45 - 50)	13.5	17.9	32.6	36.1
IIBCk	20 - 22 (50 - 55)	8.4	8.5	21.4	61.6
	22 - 24 (55 - 62)	10.2	17.0	17.6	55.2
IIIBCk	24 - 28 (62 - 71)	13.8	23.6	15.7	46.9
	28 - 30 (71 - 77)	25.6	42.8	13.2	18.4
	30 - 34 (77 - 87)	24.3	42.1	13.7	19.6
IVCk	34 - 40 (87-103)	3.5	7.4	17.0	72.1

TABLE A-12. PARTICLE SIZE DISTRIBUTION OF THE SOIL PROFILE FROM THE Ca SLUDGE ON THE ELORA CORN PLOTS.

Horizon	Depth Inches (cm)	% of < 2000 μ fraction			
		<2	2 - 20	20 - 50	50 - 2000
Ap	0 - 6 (0 - 15)	13.4	34.1	31.0	21.5
	6 - 8 (15 - 20)	14.1	32.0	34.5	19.4
	8 - 10 (20 - 25)	11.9	34.7	32.4	21.0
	10 - 12 (25 - 30)	12.3	32.8	33.6	21.3
Ae1	12 - 14 (30 - 35)	18.5	29.0	37.2	15.3
	14 - 16 (35 - 40)	16.9	22.5	35.6	24.9
	16 - 18 (40 - 45)	15.5	19.4	35.2	29.9
	18 - 20 (45 - 50)	14.2	17.8	32.2	35.9
Ae2	20 - 22 (50 - 55)	12.5	13.3	28.9	45.4
	22 - 24 (55 - 60)	11.2	12.9	23.9	52.0
IIBmg	24 - 26 (60 - 65)	12.3	12.6	19.5	55.6
	26 - 28 (65 - 70)	9.4	11.2	20.1	59.3
IIICkg	28 - 30 (70 - 75)	14.0	13.8	20.0	52.3
	30 - 33 (75 - 85)	11.6	14.8	19.4	54.2
	33 - 37 (85 - 95)	13.5	16.0	20.4	50.0
	37 - 41 (95 - 105)	14.5	18.1	23.3	44.1

TABLE A-13. PARTICLE SIZE DISTRIBUTION OF THE SOIL PROFILE FROM THE Fe SLUDGE ON THE CAMBRIDGE CORN PLOTS.

Horizon	Depth Inches (cm)	% of < 2000 μ fraction			
		<2	2 - 20	20 - 50	50 - 2000
Ap	0 - 6 (0 - 15)	9.2	10.5	11.3	69.0
	6 - 8 (15 - 20)	10.0	10.6	11.1	68.3
Ae	8 - 10 (20 - 25)	9.0	7.7	7.8	75.5
AeBt	10 - 12 (25 - 30)	11.3	5.7	6.0	77.0
Bt	12 - 14 (30 - 35)	13.6	5.1	5.8	76.4
	14 - 16 (35 - 41)	14.7	-	-	75.1
	16 - 19 (41 - 48)	12.5	3.2	4.3	80.0
IICk	19 - 22 (48 - 56)	3.2	1.8	3.2	91.8
	22 - 24 (56 - 61)	2.8	1.8	2.7	92.7
	24 - 26 (61 - 66)	2.9	1.4	1.6	94.2
	26 - 30 (66 - 76)	2.7	.7	1.3	95.3
	30 - 34 (76 - 86)	2.9	.1	1.8	95.2
	34 - 37 (86 - 94)	2.2	1.3	1.4	95.0
	37 - 40 (94 - 102)	2.7	.4	1.0	96.0
IIICk	40 - 44 (102 - 112)	3.3	-	-	96.3
	44 - 48 (112 - 122)	1.0	.3	68.4	30.4

TABLE A-14. PARTICLE SIZE DISTRIBUTION OF THE SOIL PROFILE FROM THE Al SLUDGE ON THE CAMBRIDGE CORN PLOTS.

Horizon	Depth Inches (cm)	% of < 2000 μ fraction			
		<2	2 - 20	20 - 50	50 - 2000
Ap	0 - 5 (0 - 13)	7.8	10.1	10.3	71.9
	5 - 7 (13 - 17)	7.8	9.6	9.0	73.6
AeBm	7 - 9 (17 - 23)	5.8	11.4	10.4	72.4
Ae	9 - 11 (23 - 28)	5.3	12.0	9.5	73.2
	11 - 13 (28 - 33)	5.8	13.2	11.7	69.4
	13 - 15 (33 - 38)	5.1	11.4	10.7	72.8
	15 - 17 (38 - 43)	5.6	11.0	10.5	72.9
	17 - 19 (43 - 48)	5.8	11.3	6.6	76.3
AeBt	19 - 21 (48 - 53)	6.6	10.8	9.0	73.6
Bt	21 - 24 (53 - 61	10.1	7.2	6.5	76.2
IIBt	24 - 26 (61 - 66)	8.4	4.5	4.3	82.9
	26 - 28 (66 - 71)	7.6	3.7	3.1	85.7
	28 - 30 (71 - 76)	6.0	3.6	2.5	87.9
	30 - 32 (76 - 81)	6.1	5.8	.1	88.0
	32 - 34 (81 - 86)	8.9	3.7	2.4	85.1
	34 - 36 (86 - 91)	10.3	3.7	2.8	83.2

TABLE A-14. (CONT'D)

Horizon	Depth Inches (cm)	% of < 2000 μ fraction			
		<2	2 - 20	20 - 50	50 - 2000
	36 - 39 (91 - 99)	11.1	3.7	3.8	81.3
IIICk	39 - 45 (99 -114)	1.6	.5	2.1	95.8
IVCk	45 - 48 (114 - 122)	3.6	.7	2.1	93.6
VCk	48 - 54 (122 - 137)	1.7	.2	.8	97.3

TABLE A-15. PARTICLE SIZE DISTRIBUTION OF THE SOIL PROFILE FROM THE Ca SLUDGE ON THE CAMBRIDGE CORN PLOTS.

Horizon	Depth Inches (cm)	% of < 2000 μ fraction			
		<2	2 - 20	20 - 53	50 - 2000
Ap	0 - 7 (0 - 17)	7.8	10.6	10.0	71.6
	7 - 9 (17 - 23)	6.1	13.6	12.1	68.3
Ae	9 - 12 (23 - 30)	3.9	10.0	8.9	77.2
	12 - 14 (30 - 35)	3.9	9.3	9.8	77.0
	14 - 16 (35 - 41)	4.1	10.9	8.4	76.6
	16 - 18 (41 - 45)	4.6	10.1	10.6	74.8
	18 - 20 (45 - 50)	4.3	9.6	9.5	76.7
	20 - 22 (50 - 56)	4.3	9.3	8.8	77.7
	22 - 24 (56 - 61)	5.8	8.5	8.0	77.7
	24 - 26 (61 - 66)	5.0	6.3	5.8	82.9
	26 - 29 (66 - 73)	5.2	3.5	2.6	88.6
Bt	29 - 31 (73 - 79)	12.7	1.1	3.3	82.9
IICk	31 - 36 (79 - 91)	2.1	1.0	1.7	95.2
IIICk	36 - 37 (91 - 94)	11.4	1.8	2.4	84.4
IVCk	37 - 39 (94 - 99)	2.5	1.0	.8	95.7
VCk	39 - 40 (99 - 102)	3.7	.8	1.9	93.5
VICk	40 - 44 (102 - 112)	2.9	.6	1.6	94.9

TABLE A-15. (CONT'D)

Horizon	Depth Inches (cm)	% of < 2000 μ fraction			
		<2	2 - 20	20 - 53	50 - 2000
VIICk	44 - 48 (112 - 122)	2.5	.3	1.2	96.0
VIIICk	48 - 54 (122 - 137)	2.4	1.1	.0	96.6
IXCk	54 - 60 (137 - 152)	2.5	1.5	.1	95.9

TABLE A-16. PARTICLE SIZE DISTRIBUTION OF THE SOIL PROFILE FROM THE Fe SLUDGE ON THE MILTON CORN PLOTS.

Horizon	Depth Inches (cm)	% of < 2000 μ fraction			
		<2	2 - 20	20 - 50	50 - 2000
Ap	0 - 8 (0 - 20)	31.0	30.0	17.5	21.5
Aeg	8 - 10 (20 - 25)	33.0	28.7	17.7	20.7
Btg	10 - 12 (25 - 30)	40.4	23.7	12.7	23.2
	12 - 14 (30 - 35)	35.0	21.4	15.3	28.3
	14 - 16 (35 - 40)	35.1	26.1	17.9	20.9
IIBC	16 - 18 (40 - 45)	33.5	32.8	18.3	15.5
	18 - 20 (45 - 50)	33.9	35.4	17.1	13.6
	20 - 22 (50 - 55)	30.9	35.3	17.8	16.0
IIIC	22 - 24 (55 - 60)	28.9	35.6	17.5	18.0
	24 - 26 (60 - 65)	28.5	36.7	17.2	17.7
	26 - 28 (65 - 70)	28.1	36.8	17.6	17.5
	28 - 30 (78 - 80)	28.2	35.3	19.8	16.7
			Sub profile from Opposite Side of pit		
Aeg	7 - 9 (18 - 21)	37.2	29.7	15.2	17.9
Ahb	9 - 12 (21 - 30)	54.8	24.4	8.1	12.7
IICkg	12 - 14 (30 - 36)	50.1	24.4	11.4	15.1

TABLE A-17. PARTICLE SIZE DISTRIBUTION OF THE SOIL PROFILE FROM THE Al SLUDGE ON THE MILTON CORN PLOTS.

Horizon	Depth Inches (cm)	% of < 2000 μ fraction			
		<2	2 - 20	20 - 50	50 - 2000
Ap	0 - 8 (0 - 20)	36.3	28.1	16.8	18.8
Ae	8 - 10 (20 - 25)	44.0	26.8	12.8	16.4
Bt	10 - 12 (25 - 30)	40.9	26.6	14.3	18.2
	12 - 14 (30 - 35)	39.1	26.1	14.8	20.0
	14 - 16 (35 - 40)	36.4	26.3	14.2	23.1
IIBC	16 - 18 (40 - 45)	26.2	29.3	21.4	22.4
IIC	18 - 20 (45 - 50)	26.4	30.1	21.0	21.9
	20 - 22 (50 - 55)	25.4	32.1	20.6	22.0
	22 - 24 (55 - 60)	24.5	33.4	20.1	21.3
	24 - 28 (60 - 70)	26.8	34.3	17.6	22.9
	28 - 32 (70 - 80)	27.8	32.5	16.9	11.8

TABLE A-18. PARTICLE SIZE DISTRIBUTION OF THE SOIL PROFILE FROM THE Ca SLUDGE ON THE MILTON CORN PLOTS.

Horizon	Depth Inches (cm)	% of < 2000 μ fraction			
		<2	2 - 20	20 - 50	50 - 2000
Ap	0 - 8 (0 - 20)	30.1	32.3	17.8	19.8
Ae	8 - 10 (20 - 25)	42.9	27.8	12.6	16.7
Bt	10 - 12 (25 - 30)	43.9	27.1	13.7	16.4
	12 - 14 (30 - 35)	42.9	26.3	12.7	18.1
	14 - 16 (35 - 40)	34.9	22.6	13.2	29.4
IIBC	16 - 18 (40 - 45)	29.1	26.3	15.3	29.3
	18 - 20 (45 - 50)	29.7	28.8	18.7	22.8
	20 - 22 (50 - 55)	27.9	32.8	19.3	20.1
IIC	22 - 24 (55 - 60)	28.2	31.4	18.8	21.7
	24 - 26 (60 - 65)	27.8	32.7	19.2	20.4
	26 - 28 (65 - 70)	26.4	33.8	17.9	22.0
	28 - 30 (70 - 80)	27.7	32.6	17.5	22.1
	30 - 32 (80 - 90)	25.2	33.2	19.5	22.1
	36 - 40 (90 - 100)	24.0	33.6	19.9	22.6

TABLE A-19. $CaCO_3$ EQUIVALENT, pH, NH_4-OXALATE AND Na-DITHIONITE-EXTRACTABLE Fe, Al AND Mn IN THE SOIL PROFILE FROM THE Fe SLUDGE ON THE ELORA CORN PLOTS.

Horizon	Depth inches (cm)	% $CaCO_3$ Equiv.	pH		Oxalate (%)			Dithionite (%)		
			(1:1 water)	$CaCl_2$	Fe	Al	Mn	Fe	Al	Mn
Ap	0-6 (0-15)	1.4	7.5	7.1	.57	.25	.051	1.34	.22	.06
	6-8 (15-21)	1.3	7.6	7.3	.42	.32	.056	1.24	.29	.06
Ae	8-10 (21-26)	.3	7.8	7.5	.41	.24	.072	1.26	.26	.11
	10-12 (26-30)	.1	7.7	7.6	.30	.17	.063	1.08	.18	.10
	12-14 (30-35)	.1	7.7	7.6	.27	.16	.056	1.16	.19	.07
Bm	14-16 (35-41)	.3	7.8	7.6	.25	.15	.053	1.10	.16	.06
II BC	16-19 (41-47)	9.4	8.0	7.7	.21	.11	.025	.72	.12	.04
III BC	19-22 (47-57)	13.1	8.2	7.8	.23	.12	.028	.70	.13	.04
	22-26 (57-67)	17.5	8.4	7.9	.21	.11	.022	.64	.11	.05
	26-30 (67-77)	9.7	8.4	7.9	.28	.15	.036	.90	.17	.05
IV Ck	30-38 (77-97)	50.2	8.5	7.9	.17	.05	.004	.36	.06	.03

TABLE A-20. $CaCO_3$ EQUIVALENT, pH, NH_4-OXALATE AND Na-DITHIONITE-EXTRACTABLE Fe, Al AND Mn IN THE SOIL PROFILE FROM THE Al SLUDGE ON THE ELORA CORN PLOTS.

Horizon	Depth inches (cm)	% $CaCO_3$ Equiv.	pH (1:1) water	pH $CaCl_2$	Oxalate (%) Fe	Oxalate (%) Al	Oxalate (%) Mn	Dithionite (%) Fe	Dithionite (%) Al	Dithionite (%) Mn
Ap	0-2 (0-5)	1.2	7.5	7.3	.45	.42	.061	1.07	.37	.07
	2-8 (5-20)	1.2	7.5	7.4	.44	.51	.061	1.16	.48	.06
	8-10 (20-25)	0.6	7.7	7.5	.42	.39	.058	.90	.25	.07
Ae	10-12 (25-30)	0.0	7.9	7.6	.28	.18	.064	1.26	.28	.05
	12-14 (30-35)	0.2	8.0	7.6	.28	.18	.057	1.34	.26	.05
	14-16 (35-40)	0.2	8.0	7.6	.26	.17	.053	.90	.18	.08
	16-18 (40-45)	0.4	8.1	7.7	.22	.14	.063	1.06	.20	.05
Bm	18-20 (45-50)	1.8	8.1	7.7	.21	.12	.035	1.04	.19	.06
II BCk	20-22 (50-55)	16.8	8.2	7.7	.15	.07	.021	.52	.09	.03
	22-24 (55-62)	37.4	8.3	7.8	.11	.05	.011	.40	.06	.03
III BCk	24-28 (62-71)	34.8	8.5	7.9	.17	.09	.009	.38	.07	.03

TABLE A-20. (CONT'D)

Horizon	Depth inches (cm)	% $CaCO_3$ Equiv.	pH (1:1 water)	pH $CaCl_2$	Oxalate (%) Fe	Oxalate (%) Al	Oxalate (%) Mn	Dithionite (%) Fe	Dithionite (%) Al	Dithionite (%) Mn
	28-30 (71-77)	33.1	8.5	7.9	.15	.09	.012	.75	.10	.04
	30-34 (77-87)	31.3	8.5	7.9	.20	.13	.013	.60	.12	.04
IV Ck	34-40 (87-103)	48.4	8.6	7.9	.11	.03	.003	.24	.04	.02

TABLE A-21. $CaCO_3$ EQUIVALENT, pH, NH_4-OXALATE AND Na-DITHIONITE-EXTRACTABLE Fe, Al AND Mn IN THE SOIL PROFILE FROM THE Ca SLUDGE ON THE ELORA CORN PLOTS.

Horizon	Depth inches (cm)	% $CaCO_3$ Equiv.	pH (1:1 water)	pH $CaCl_2$	Oxalate (%) Fe	Oxalate (%) Al	Oxalate (%) Mn	Dithionite (%) Fe	Dithionite (%) Al	Dithionite (%) Mn
Ap	0-6 (0-15)	1.9	7.7	7.5	.35	.24	.053	1.04	.19	.08
	6-8 (15-20)	1.8	7.7	7.5	.38	.30	.070	.99	.19	.10
	8-10 (20-25)	0.8	7.6	7.4	.42	.34	.098	1.24	.27	.13
	10-12 (25-30)	0.5	7.5	7.4	.49	.47	.156	1.44	.36	.07
Ae 1	12-14 (30-35)	0.4	7.5	7.3	.40	.32	.076	1.36	.29	.05
	14-16 (35-40)	0.2	7.5	7.3	.29	.23	.040	1.16	.25	.05
	16-18 (40-45)	0.3	7.6	7.3	.23	.19	.043	1.10	.22	.07
	18-20 (45-50)	0.2	7.6	7.3	.26	.17	.058	1.08	.20	.04
Ae 2	20-22 (50-55)	1.3	7.6	7.3	.28	.20	.042	.94	.19	.04
	22-24 (55-60)	1.7	7.7	7.3	.22	.11	.033	.86	.14	.04
II Bmg	24-26 (60-65)	6.8	7.7	7.4	.25	.13	.028	.82	.12	.03

TABLE A-21. (CONT'D)

Horizon	Depth inches (cm)	% $CaCO_3$ Equiv.	pH (1:1 water)	pH $CaCl_2$	Oxalate (%) Fe	Oxalate (%) Al	Oxalate (%) Mn	Dithionite (%) Fe	Dithionite (%) Al	Dithionite (%) Mn
III Ckg	26-28 (65-70)	6.4	7.7	7.4	.21	.09	.018	.74	.10	.04
	28-30 (70-75)	5.8	7.9	7.5	.23	.11	.016	.80	.11	.04
	30-33 (75-85)	25.7	8.0	7.6	.17	.08	.015	.50	.08	.04
	33-37 (85-95)	24.8	8.3	7.9	.18	.10	.009	.56	.10	.04
	37-41 (95-105)	26.0	8.4	7.9	.19	.10	.020	.48	.08	.05

TABLE A-22. $CaCO_3$ EQUIVALENT, pH, NH_4-OXALATE AND Na-DITHIONITE-EXTRACTABLE Fe, Al AND Mn IN THE SOIL PROFILE FROM THE Fe SLUDGE ON THE CAMBRIDGE CORN PLOTS.

Horizon	Depth inches (cm)	% $CaCO_3$ Equiv.	pH		Oxalate (%)			Dithionite (%)		
			(1:1 water)	$CaCl_2$	Fe	Al	Mn	Fe	Al	Mn
Ah	0-6 (0-15)	.07	7.1	6.9	.57	.24	.056	.92	.16	.07
	6-8 (15-20)	1.3	7.0	7.0	.62	.29	.062	.80	.15	.07
Ae	8-10 (20-25)	0.2	7.4	7.4	.34	.18	.060	.84	.14	.06
Ae Bt	10-12 (25-30)	2.9	7.5	7.5	.35	.21	.063	.86	.14	.08
Bt	12-14 (30-35)	5.6	7.5	7.5	.49	.26	.067	1.18	.18	.08
	14-16 (35-41)	7.1	7.5	7.5	.50	.27	.062	1.29	.20	.09
	16-19 (41-48)	8.3	7.6	7.6	.38	.22	.047	1.04	.16	.07
II Ck	19-22 (48-56)	42.5	7.7	7.6	.14	.06	.010	.30	.05	.04
	22-24 (56-61)	46.1	7.8	7.6	.12	.05	.007	.26	.03	.03
	24-26 (61-66)	47.2	8.0	7.6	.14	.04	.007	.28	.03	.03
	26-30 (66-76)	45.5	8.0	7.6	.09	.03	.008	.24	.03	.02

TABLE A-22. (CONT'D)

Horizon	Depth inches (cm)	% $CaCo_3$ Equiv.	pH		Oxalate (%)			Dithionite (%)		
			(1:1 water)	$CaCl_2$	Fe	Al	Mn	Fe	Al	Mn
	30-34 (76-86)	46.0	8.0	7.6	.08	.03	.008	.20	.03	.02
	34-37 (86-94)	46.4	8.1	7.6	.09	.02	.07	.22	.03	.02
	37-40 (94-102)	46.4	8.1	7.6	.11	.03	.006	.22	.02	.02
III Ck	40-44 (102-112)	18.3	8.1	7.6	.05	.03	.004	.13	.02	.01
	44-48 (112-122)	19.2	8.2	7.6	.07	.04	.004	.14	.04	.01

TABLE A-23. $CaCO_3$ EQUIVALENT, pH, NH_4-OXALATE AND Na-DITHIONITE-EXTRACTABLE Fe, Al AND Mn IN THE SOIL PROFILE FROM THE Fe SLUDGE ON THE CAMBRIDGE CORN PLOTS.

Horizon	Depth inches (cm)	% $CaCO_3$ Equiv.	pH		Oxalate (%)			Dithionite (%)		
			(1:1 water)	$CaCl_2$	Fe	Al	Mn	Fe	Al	Mn
Ap	0-5 (0-13)	1.3	7.4	7.2	.37	.24	.049	.71	.23	.06
	5-7 (13-17)	1.5	7.5	7.2	.39	.17	.054	.72	.15	.06
Ae Bm	7-9 (17-23)	1.8	7.5	7.2	.36	.18	.041	.62	.14	.05
Ae	9-11 (23-28)	3.5	7.5	7.2	.33	.16	.047	.62	.14	.04
	11-13 (28-33)	0.5	7.6	7.2	.33	.16	.042	.60	.14	.05
	13-15 (33-38)	0.5	7.6	7.2	.32	.15	.045	.60	.13	.06
	15-17 (38-43)	0.4	7.6	7.2	.33	.15	.045	.61	.14	.05
	17-19 (43-48)	0.2	7.5	7.2	.35	.15	.047	.67	.14	.06
Ae Bt	19-21 (48-53)	0.2	7.4	7.2	.38	.15	.051	.80	.15	.06
Bt	21-24 (53-61)	0.6	7.4	7.2	.48	.20	.067	1.05	.19	.07
II Bt	24-26 (61-66)	0.2	7.4	7.2	.45	.19	.058	.99	.16	.06

TABLE A-23. (CONT'D)

Horizon	Depth inches (cm)	% $CaCO_3$ Equiv.	pH		Oxalate (%)			Dithionite (%)		
			(1:1 water)	$CaCl_2$	Fe	Al	Mn	Fe	Al	Mn
	26-28 (66-71)	.05	7.4	7.2	.44	.21	.056	.96	.17	.05
	28-30 (71-76)	2.0	7.5	7.3	.36	.16	.043	.80	.14	.04
	30-32 (76-81)	0.5	7.5	7.2	.34	.19	.036	.72	.16	.05
	32-34 (81-86)	0.5	7.4	7.2	.41	.18	.048	.93	.18	.06
	34-36 (86-91)	0.4	7.4	7.2	.43	.20	.048	.96	.19	.06
	36-39 (91-99)	0.7	7.4	7.2	.49	.22	.056	1.04	.20	.16
III Ck	39-45 (99-114)	45.6	7.6	7.4	.13	.04	.006	.25	.03	.02
IV Ck	45-48 (114-122)	3.8	7.6	7.4	.15	.08	.012	.28	.06	.02
V Ck	48-54 (122-137)	17.6	7.8	7.4	.07	.04	.005	.13	.03	.01

TABLE A-24. $CaCO_3$ EQUIVALENT, pH, NH_4-OXALATE AND Na-DITHIONITE-EXTRACTABLE Fe, Al AND Mn IN THE SOIL PROFILE FROM THE Ca SLUDGE ON THE CAMBRIDGE CORN PLOTS.

Horizon	Depth inches (cm)	% $CaCO_3$ Equiv.	pH (1:1 water)	pH $CaCl_2$	Oxalate (%) Fe	Oxalate (%) Al	Oxalate (%) Mn	Dithionite (%) Fe	Dithionite (%) Al	Dithionite (%) Mn
Ap	0-7 (0-17)	5.8	7.7	7.6	.36	.19	.036	.60	.16	.05
	7-9 (17-23)	5.6	7.8	7.5	.35	.18	.043	.58	.12	.05
Ae	9-12 (23-30)	0.1	8.0	7.5	.28	.22	.021	.57	.16	.01
	12-14 (30-35)	0.0	8.0	7.5	.29	.21	.020	.54	.16	.01
	14-16 (35-41)	0.0	8.0	7.5	.30	.21	.024	.55	.17	.02
	16-18 (41-45)	0.0	7.9	7.4	.27	.16	.021	.51	.14	.01
	18-20 (45-50)	0.0	8.0	7.4	.28	.16	.019	.50	.12	.03
	20-22 (50-56)	0.0	7.9	7.4	.26	.14	.021	.50	.09	.01
	22-24 (56-61)	0.0	8.0	7.4	.25	.13	.022	.48	.10	.02
	24-26 (61-66)	0.1	7.9	7.4	.19	.09	.022	.44	.08	.01
	26-29 (66-73)	2.0	7.9	7.4	.20	.11	.024	.37	.07	.03

TABLE A-24. (CONT'D)

Horizon	Depth inches (cm)	% $CaCO_3$ Equiv.	pH (1:1 water)	pH $CaCl_2$	Oxalate (%) Fe	Oxalate (%) Al	Oxalate (%) Mn	Dithionite (%) Fe	Dithionite (%) Al	Dithionite (%) Mn
Bt	29-31 (73-79)	0.8	7.8	7.4	.43	.22	.045	.98	.16	.06
II Ck	31-36 (79-91)	32.0	8.0	7.4	.12	.03	.006	.18	.02	.01
III Ck	36-37 (91-94)	1.4	7.8	7.5	1.33	.12	.015	1.62	.08	.03
IV Ck	37-39 (94-99)	32.5	8.1	7.5	.23	.03	.006	.40	.03	.01
V Ck	39-40 (99-102)	12.6	8.0	7.5	1.50	.07	.009	1.22	.05	.01
VI Ck	40-44 (102-112)	29.2	8.3	7.5	.13	.04	.006	.19	.02	.01
VII Ck	44-48 (112-122)	20.1	8.2	7.5	.08	.04	.004	.16	.02	.01
VIII Ck	48-54 (122-137)	20.0	8.2	7.5	.16	.03	.004	.20	.02	.01
IX Ck	54-60 (137-152)	19.5	8.2	7.5	.07	.04	.004	.13	.02	.01

TABLE A-25. $CaCO_3$ EQUIVALENT, pH, NH_4-OXALATE AND Na-DITHIONITE-EXTRACTABLE Fe, Al AND Mn IN THE SOIL PROFILE FROM THE Fe SLUDGE ON THE MILTON CORN PLOTS.

			pH		Oxalate (%)			Dithionite (%)		
Horizon	Depth inches (cm)	% $CaCO_3$ Equiv.	(1:1 water)	$CaCl_2$	Fe	Al	Mn	Fe	Al	Mn
Ap	0-8 (6-20)	0.0	6.9	6.7	1.17	.28	.105	1.84	.32	.11
Aeg	8-10 (20-25)	0.2	7.0	6.7	.91	.29	.092	1.91	.33	.10
Btg	10-12 (25-30)	0.1	7.0	6.5	.79	.27	.041	1.90	.23	.05
	12-14 (30-35)	0.2	7.0	6.5	.73	.28	.064	1.82	.38	.06
	14-16 (35-40)	0.2	7.2	6.7	.66	.26	.061	1.74	.28	.07
IIBC	16-18 (40-45)	0.8	7.5	6.9	.46	.20	.088	1.64	.25	.09
	18-20 (45-50)	0.6	7.8	7.2	.45	.24	.079	1.35	.16	.08
	20-22 (50-55)	5.8	8.0	7.5	.34	.18	.052	1.40	.22	.07
IIIC	22-24 (55-60)	10.5	8.1	7.6	.35	.22	.036	1.18	.23	.06
	24-26 (60-65)	12.8	8.2	7.6	.28	.14	.033	1.16	.19	.06
	26-28 (65-70)	13.4	8.3	7.7	.28	.15	.029	1.20	.19	.06
	28-30 (70-80)	15.3	8.3	7.7	.26	.14	.029	1.20	.33	.06

TABLE A-25. (CONT'D)

Subprofile from opposite side of pit

Horizon	Depth inches (cm)	% $CaCO_3$ Equiv.	pH (1:1 water)	pH $CaCl_2$	Oxalate (%) Fe	Oxalate (%) Al	Oxalate (%) Mn	Dithionite (%) Fe	Dithionite (%) Al	Dithionite (%) Mn
Aeg	7-9 (18-21)	0.0	6.6	6.2	.92	.32	.085	1.73	0.33	.10
Ahb	9-12 (21-30)	0.0	5.5	5.0	.91	.51	.026	1.56	0.48	.03
IIICkg	12-14 (30-36)	0.4	5.9	5.4	.95	.31	.008	1.60	0.26	.01

TABLE A-26. $CaCO_3$ EQUIVALENT, pH, NH_4-OXALATE AND Na-DITHIONITE-EXTRACTABLE Fe, Al AND Mn IN THE SOIL PROFILE FROM THE Al SLUDGE ON THE MILTON CORN PLOTS.

Horizon	Depth inches (cm)	% $CaCO_3$ Equiv.	pH (1:1 water)	pH $CaCl_2$	Oxalate (%) Fe	Oxalate (%) Al	Oxalate (%) Mn	Dithionite (%) Fe	Dithionite (%) Al	Dithionite (%) Mn
Ap	0-8 (0-20)	0.4	7.4	7.1	.89	.32	.085	1.50	.25	.09
Ae	8-10 (20-25)	0.0	7.6	7.2	.72	.29	.059	1.84	.30	.06
Bt	10-12 (25-30)	0.0	7.6	7.2	.49	.23	.063	1.86	.32	.07
	12-14 (30-35)	0.0	7.7	7.3	.50	.27	.062	1.74	.29	.06
	14-16 (35-40)	2.5	7.8	7.4	.42	.25	.046	1.48	.24	.05
IIBC	16-18 (40-45)	10.1	7.9	7.6	.34	.16	.039	1.24	.20	.06
IIC	18-20 (45-50)	12.9	8.0	7.7	.24	.12	.040	.96	.14	.07
	20-22 (50-55)	13.5	8.0	7.7	.28	.14	.032	.80	.12	.07
	22-24 (55-60)	14.4	8.0	7.8	.24	.13	.035	1.20	.17	.07
	24-28 (60-70)	15.0	8.0	7.8	.26	.15	.031	1.04	.18	.06
	28-32 (70-80)	15.4	8.0	7.9	.29	.14	.029	1.13	0.20	.06

TABLE A-27. $CaCO_3$ EQUIVALENT, pH, NH_4-OXALATE AND Na-DITHIONITE-EXTRACTABLE Fe, Al AND Mn IN THE SOIL PROFILE FROM THE Ca SLUDGE ON THE MILTON CORN PLOTS.

Horizon	Depth inches (cm)	% $CaCO_3$ Equiv.	pH (1:1 water)	pH $CaCl_2$	Oxalate (%) Fe	Oxalate (%) Al	Oxalate (%) Mn	Dithionite (%) Fe	Dithionite (%) Al	Dithionite (%) Mn
Ap	0-8 (0-20)	2.8	7.8	7.8	.88	.28	.078	1.68	.28	.08
Ae	8-10 (20-25)	2.4	7.9	7.8	.69	.28	.059	-	-	.07
Bt	10-12 (25-30)	0.2	7.9	7.8	.48	.27	.084	1.31	.19	.10
	12-14 (30-35)	0.4	7.9	7.8	.40	.23	.074	1.91	.30	.08
	14-16 (35-40)	1.4	7.9	7.8	.32	.22	.046	1.56	.24	.05
II BC	16-18 (40-45)	10.0	8.0	7.8	.27	.16	.037	1.24	.18	.05
	18-20 (45-50)	8.5	8.1	7.8	.31	.16	.045	1.34	.19	.06
	20-22 (50-55)	11.0	8.1	7.8	.34	.19	.036	1.28	.19	.07
II C	22-24 (55-60)	13.0	8.2	7.9	.24	.14	.038	1.78	.26	.07
	24-26 (60-65)	15.2	8.3	7.9	.22	.12	.037	1.11	.15	.07
	26-28 (65-70)	13.5	8.3	7.9	.26	.14	.035	1.16	.18	.07

TABLE A-27. (CONT'D)

Horizon	Depth inches (cm)	% $CaCO_3$ Equiv.	pH		Oxalate (%)			Dithionite (%)		
			(1:1 water)	$CaCl_2$	Fe	Al	Mn	Fe	Al	Mn
	28-32 (70-80)	13.7	8.3	7.9	.23	.13	.029	.82	.08	.06
	32-36 (80-90)	14.1	8.3	7.9	.26	.14	.031	.95	.12	.06
	36-40 (90-100)	16.8	8.3	7.9	.22	.11	.034	1.14	.22	.06

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